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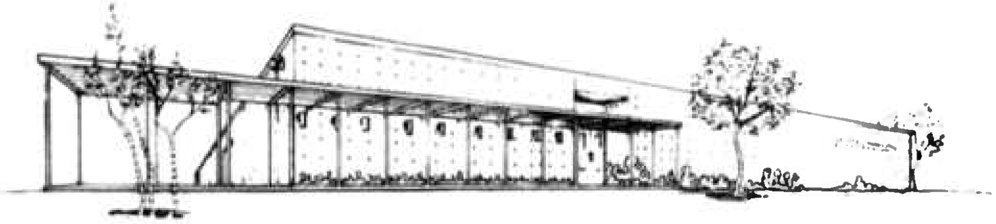
TECHNICAL REPORT NO. 63-99

SEMIANNUAL REPORT NO. 5, PROJECT VT/1139



THE GEOTECHNICAL CORPORATION

3401 SHILOH ROAD GARLAND, TEXAS

GEOTECH

(5) 362 200

(14) Rept. no. TR

TECHNICAL REPORT NO. 63-99

(9) SEMIANNUAL REPORT NO. 5, PROJECT VT/1139

THE GEOTECHNICAL CORPORATION
3401 Shiloh Road
Garland, Texas

(11) 15 December 1963

IDENTIFICATION

6

AFTAC Project No: VT/1139
Project Title: Deep-Hole Seismometer
ARPA Order ~~No~~: 104
ARPA Project Code No: 8100
Contractor: The Geotechnical Corporation, Garland, Texas
Date of Contract: 11 March 1963 Phase III
Amount of Contract: $1,479,775.00 Phase III
15 Contract [redacted] AF 33(600)-43369
Contract Expiration Date: 30 June 1964
Project Engineer: Richard M. Shappee, BR8-8102

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ILLUSTRATIONS, (Continued)

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ILLUSTRATIONS, (Continued)

ILLUSTRATIONS, (Continued)

ABSTRACT

Surface noise was measured at 25 locations and used as an aid in the selection of deep-well sites. Four deep-well sites were found with amplitudes sufficiently low to make them worth further consideration. ~~All known details were summarized and specific recommendations were made to AFTAC for their preparation. Approval was received for the preparation of one well in Nevada and one well in Wyoming.~~

Field measurements were made at deep-well sites near Orlando, Florida, on Eniwetok Atoll, and near Apache, Oklahoma. ~~Two winch trucks and cables were purchased to replace leased equipment. Skid-mounted winches were purchased for use at the Grapevine, Texas, test site, and experiments were performed. Among these was the operation of two deep-well instruments on separate cables in the deep well. Design improvements were made to the seismograph at Grapevine, and these improvements were incorporated into the seismographs operated at the other deep-well sites to improve reliability, accuracy, and ease of operation.~~

A deep-well site at the Uinta Basin Seismological Observatory, Vernal, Utah, was located and prepared for use.

Data recorded at the deep-well sites were visually analyzed and spectral analyses were made of the magnetic-tape recordings. Theoretical work was done at the Data Analysis and Technique Development Center (DATAC) using measured and assumed velocities of the layers of earth at the well sites. Comparison of the theoretical results with those of the measurement program suggests the need to consider layers much deeper in the earth than previously believed necessary.

A processing system was developed to permit summation, filtering, or delaying of signals recorded from two seismometers. Signals recorded from two seismometers in the well at the Grapevine test site were processed with the system.

SEMIANNUAL REPORT NO. 5, PROJECT VT/1139

1. INTRODUCTION

This report presents the technical findings and accomplishments of Project VT/1139 from 1 June to 1 December 1963. The report is submitted in compliance with Paragraph 2, Reports, of the Statement of Work to be Done, Project VT/1139.

The main body of the report is presented in the same sequence as the tasks in the Statement of Work. A copy of the Statement of Work is included as appendix 1.

Appendix 2 of this report is a copy of the site report for the Terry No. 1 Well in Orlando, Florida. This report was prepared at the request of the Project Officer and is typical of other reports that will be written to document each well occupied as part of the project.

2. INVESTIGATE AND CATALOG EXISTING DEEP WELLS, TASK 1h (1)

2.1 INVESTIGATION OF DEEP WELLS

2.1.1 At the beginning of the reporting period, five wells had been approved by AFTAC for field measurements. These wells and their geological environments are as follows:

a. Terry No. 1 in Orange County, Florida, in the Southern Atlantic Coastal Plain near the Atlantic coast;

b. Perdasofpy No. 1 in Comanche County, Oklahoma, in an interior orogenic area;

c. Eniwetok E-1 in the Marshall Islands, on a typical Pacific coral atoll;

d. Meridian Unit No. 1 in White Pine County, Nevada, in a typical block-faulted area of the Basin and Range province;

e. The Trigg No. 1 well in Dallas County, Texas, fairly typical of the Southern Coastal Plains, approved by AFTAC in an earlier phase of Project VT/1139.

Figure 1 shows the locations of the four wells within the Continental United States.

2.1.2 During the reporting period, existing wells were investigated within the following areas of the Continental United States:

a. Rocky Mountain fold basins;

b. Sedimentary basins within the Colorado Plateau;

c. Extrusive volcanic areas, particularly the Columbia River Plateau;

d. Deep sedimentary basins of the stable continental interior, such as the Michigan and Williston Basins;

e. The Appalachian fold area;

f. The Gulf Coastal Plain and Mississippi embayment.

2.1.3 Deep wells in geological areas of interest in the Western Pacific area were investigated during the reporting period. These areas are as follows:

a. Cagayan Valley, Luzon, Phillipine Islands;

b. Great Artesian Basin, Queensland, Australia;

c. Amadeus Basin, Northern Territory, Australia;

d. Perth Basin, Western Australia;

e. Taranaki Basin, North Island, New Zealand.

UNITED STATES

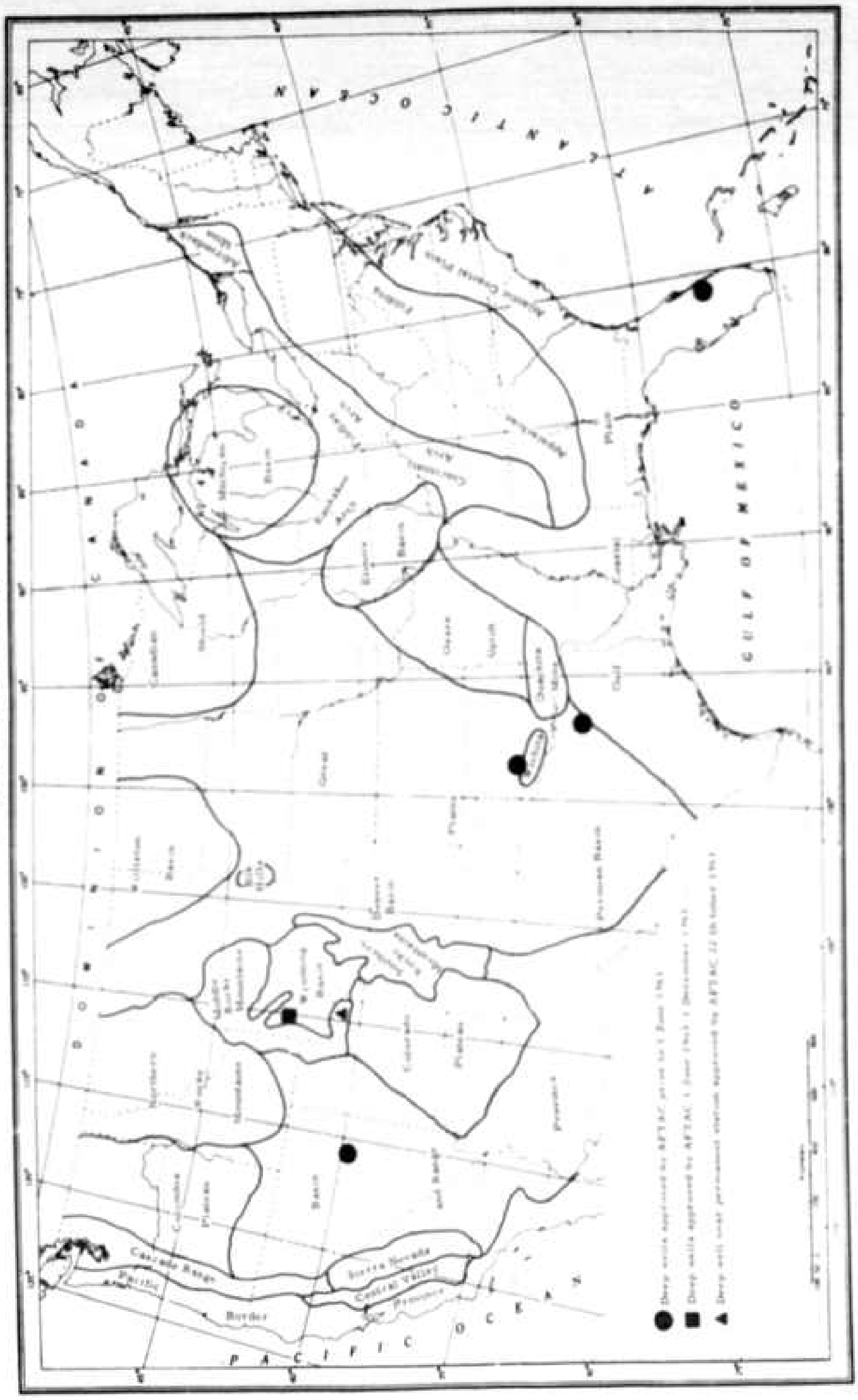


Figure 1. Locations of deep wells approved

2.1.4 The results obtained and conclusions drawn from measurements in deep wells during the reporting period were used in the refinement of well investigation criteria.

2.2 SURFACE NOISE SURVEYS AT DEEP-WELL SITES

2.2.1 A survey of surface noise was conducted at six deep-well sites in West Texas, New Mexico, and western Wyoming during the period 23 July to 6 August 1963. This was designated as Surface Noise Survey No. 2.

2.2.2 During the period 14 August to 29 August 1963, a survey of surface noise was conducted at eight deep-well sites in the Appalachian fold area. A ninth site which was visited by the survey team was found to be a gas storage well. This survey was designated as Surface Noise Survey No. 3.

2.2.3 A third surface noise survey was conducted during the period 18 October to 6 November 1963. Measurements were made at 2 deep wells in the Michigan Basin, 5 wells in the Williston Basin in North Dakota and Montana, 1 well in the Powder River Basin of Wyoming, 2 wells in the Denver-Julesburg Basin in eastern Colorado and western Kansas, and 1 well in the Forest City Basin in eastern Kansas. Four additional wells were visited by this survey team and found to be inaccessible. This survey was designated as Surface Noise Survey No. 4.

2.2.4 The results of Surface Noise Surveys 2, 3, and 4 are tabulated in figure 2. The locations of the wells surveyed are shown in figure 3.

2.3 SURFACE NOISE STUDIES OF DEEP-WELL SITES

2.3.1 A surface noise study of the United States was initiated using the results of the noise surveys at deep-well sites under consideration, LRSM data, and other available surface noise values. When completed, this study will show areas of low surface noise where deep wells exist, as well as areas where deep wells can be drilled.

2.3.2 Using the data referred to in paragraph 2.3.1 and other available information, surface noise investigations were undertaken in an attempt to determine if microseismic barriers exist within the Continental United States. Results of these studies were inconclusive at the end of the reporting period. The studies are continuing.

Well drilled by	Well No.	Well designation	County	State	Total depth/ft	Geological formation at total depth	Surface noise .3 to 1.3 second spectrum: p-p at 1 cps mμ	Surface noise .3 to 1.3 second spectrum: Predominant period sec	Noise survey date 1963
Noise Survey #2									
1. Ohio Oil Company	1	Government Haines	Sandoval	New Mexico	6,190	Pennsylvanian Sediments	3.0	0.6	26 July
2. Phillips Petroleum Company	1	Hobark	Sublette	Wyoming	13,267	Lower Cretaceous Sediments	2.5	0.6	30 July
3. Stanolind Oil & Gas Company	1	Pinedale	Sublette	Wyoming	7,994	Tertiary Sediments	3.5	0.6	31 July
4. Mountain Fuel Supply Company	1	Antelope Draw	Sublette	Wyoming	9,779	Tertiary Sediments	6.9	0.6	1 Aug
5. Phillips Petroleum Company	1	Marhleton	Sublette	Wyoming	7,162	Tertiary Sediments	1.5	0.6	1 Aug
6. Phillips Petroleum Company	1	"EE" University	Pecos	Texas	25,304	Ordovician Limestone	3.0	0.6	6 Aug
Noise Survey #3									
1. United Fuel Gas Company	1	Jasper James	Martin	Kentucky	13,172	Granite	39.0	0.4	14 Aug
2. Phillips Petroleum Company	1	Finch	Marion	West Virginia	17,111	Cambrian	10.0	0.6	16 Aug
3. Pure Oil Company	1	Blemle	Bradford	Pennsylvania	12,917	Tuscarora (Silurian)	11.0	0.7	20 Aug
4. Gulf Petroleum Company	-	Campbell	Delaware	New York	10,993	Precambrian	9.0	0.6	21 Aug
5. New York State Natural Gas Company	1	Sheperd	Tompkins	New York	10,439	Precambrian	17.5	0.5	22 Aug
6. Hope Natural Gas Company	9634	Power	Wood	West Virginia	13,331	Precambrian	12.5	0.5	27 Aug
7. Hope Natural Gas Company	10224		Randolph	West Virginia	13,121	?	13.0	0.6	29 Aug
8. United Fuel Gas Company	1	Spanaugle	Pendleton	West Virginia	13,001	Ordovician Limestone	7.5	0.6	29 Aug
Noise Survey #4									
1. C. J. Simpson & Sun Oil Company	1	Sattlebarg	Tuscola	Michigan	10,130	Cambrian	23.0	0.4	20 Oct
2. Pure Oil Company	1	Emery	Midland	Michigan	9,519	Ordovician	200.0	0.4	22 Oct
3. Carter Oil Company	1	D. Moore	Divide	North Dakota	11,040	Cambrian	42.0	0.4	25 Oct
4. Amerada Petroleum Company	1	A. Johnson	Sheridan	Montana	11,071	Cambrian	85.0	0.5	26 Oct
5. Texaco	1	Agnes Sheaser	Dawson	Montana	10,500	Ordovician	12.0	0.5	27 Oct
6. Amerada Petroleum Company	1	Marie Selle, Tr. 1	Dunn	North Dakota	12,168	Ordovician	18.0	0.5	28 Oct
7. Pan American	1	Raymond Vetter	Morton	North Dakota	11,212	Cambrian	22.0	0.5	29 Oct
8. E. M. Davis	1	Miller	Campbell	Wyoming	10,200	Pennsylvanian	19.0	0.5	30 Oct
9. Standard Oil of California	1	L. Mamm	Yuma	Colorado	6,512	Granite	9.5	0.5	3 Nov
10. Texaco	1	Pearce	Wallace	Kansas	6,058	Granite	12.0	0.5	4 Nov
11. Neuner	1	Emmett	Douglas	Kansas	2,832	Granite	15.0	0.5	6 Nov

Figure 2 Surface noise surveys conducted at deep-well sites

UNITED STATES

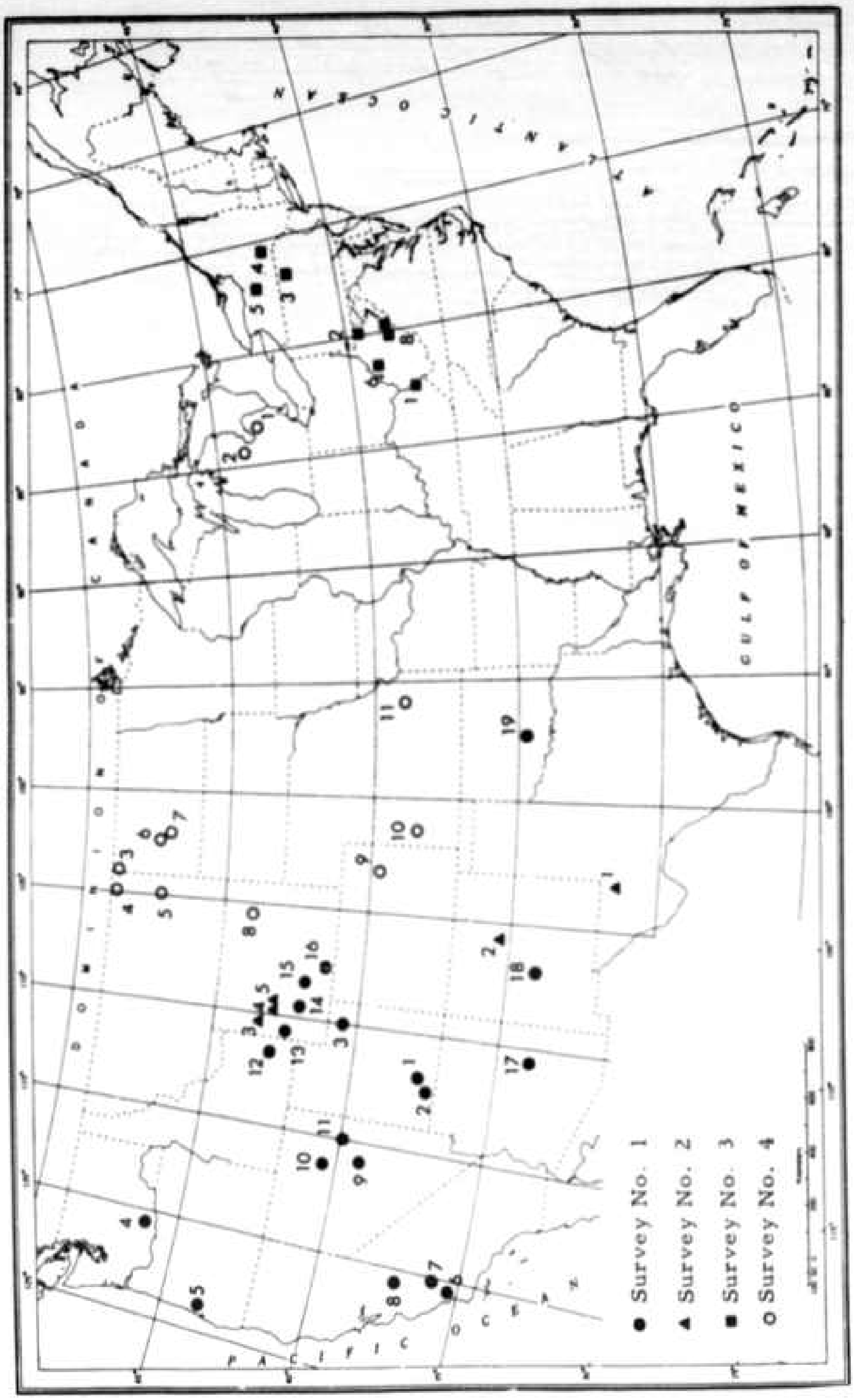


Figure 3. Map of the United States showing locations of the wells at which noise surveys were conducted

2.4 SPECIAL STUDIES

During the reporting period, studies were initiated to establish the relationships between surface noise levels and tectonic environment. At the end of the reporting period, these studies were not sufficiently complete to present conclusive results and contour maps. The studies are continuing and the results will be presented in subsequent reports.

2.5 CATALOGING OF DEEP WELLS

Four deep wells were cataloged during the reporting period. One hundred-one deep wells were investigated. At the close of the reporting period, 2 wells were in the process of being cataloged and 25 were under investigation. Figure 4 is a map of the United States showing the well catalog coverage at the close of the reporting period. Well catalog technique and design was broadened and improved. Figures 5, 6, and 7 are typical catalog presentations.

3. SITES PREPARED AND OCCUPIED, TASK 1h (2)

3.1 SITES SELECTED AND APPROVED

On 9 September 1963, AFTAC approved the Stanolind No. 1 Pinedale well, Sublette County, Wyoming, for deep well preparation. This well has a depth of 7,794 ft (2,375 m).

Simultaneously with the approval of this well, announcement was made of immediate plans for drilling Mountain Fuel No. 8 Pinedale, a 10,500-ft (3,202-m) test well about a mile (1.6 km) away. It was decided to arrange to take over the well if it were a dry hole, in preference to re-entering the Stanolind No. 1 Pinedale. This decision was made because of the greater depth of the No. 8 Pinedale and the possibility that it could be prepared more economically than the No. 1 Pinedale. The Pinedale No. 8 well was drilled at approximately 9,600 ft (2,925 m) at the end of the reporting period. An alternate dry hole may be re-entered if the No. 8 Pinedale is a producer. It is Texaco No. 1 Tabernacle Butte, 11,000 ft (3,355 m) deep, about 20 miles (32 km) distant completed in April 1963. All three wells penetrate comparable geological sections of the Green River Basin, and are equally accessible.

Figure 4. Map showing well catalog coverage of the United States

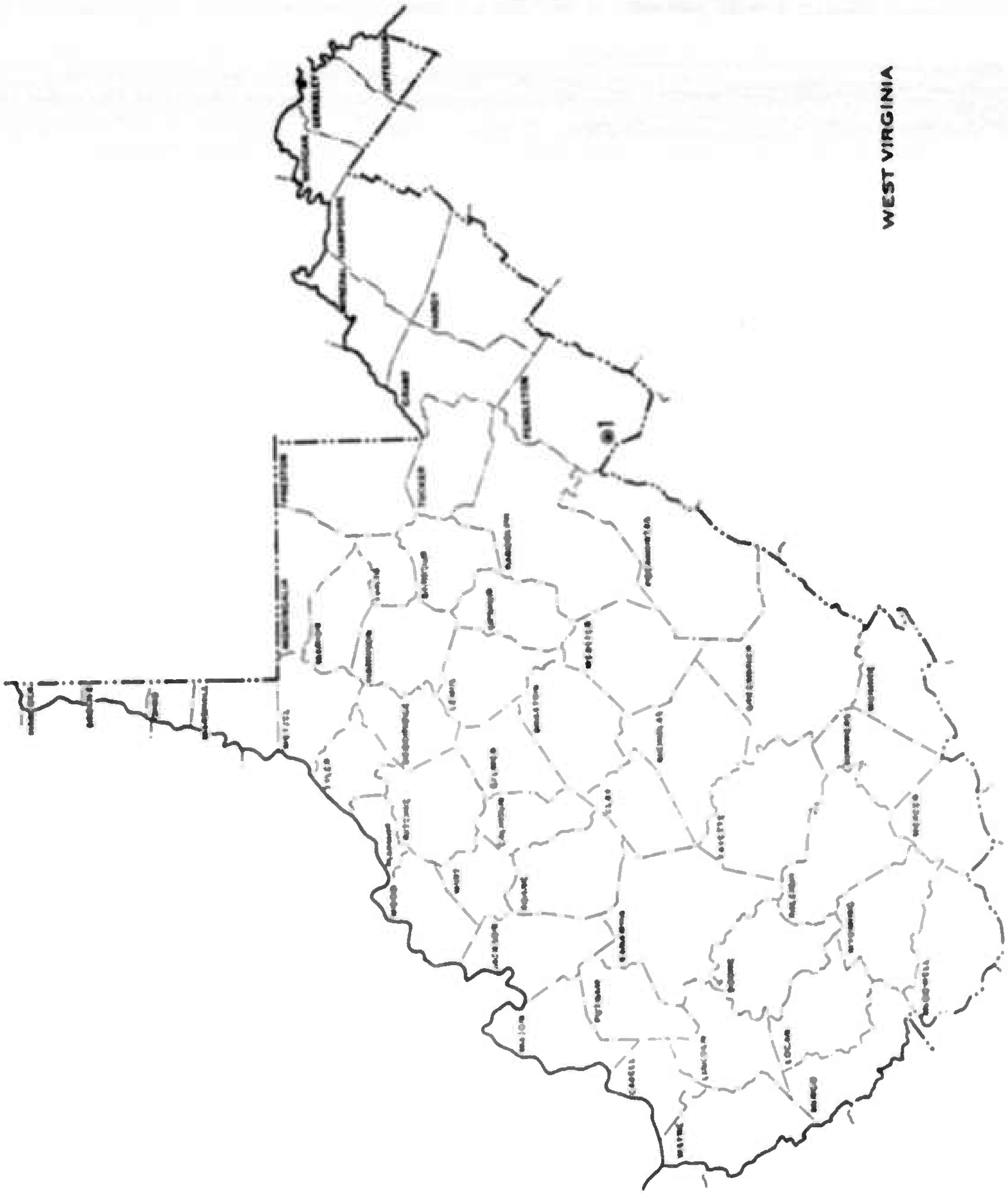


Figure 5. State map showing well location, well catalog

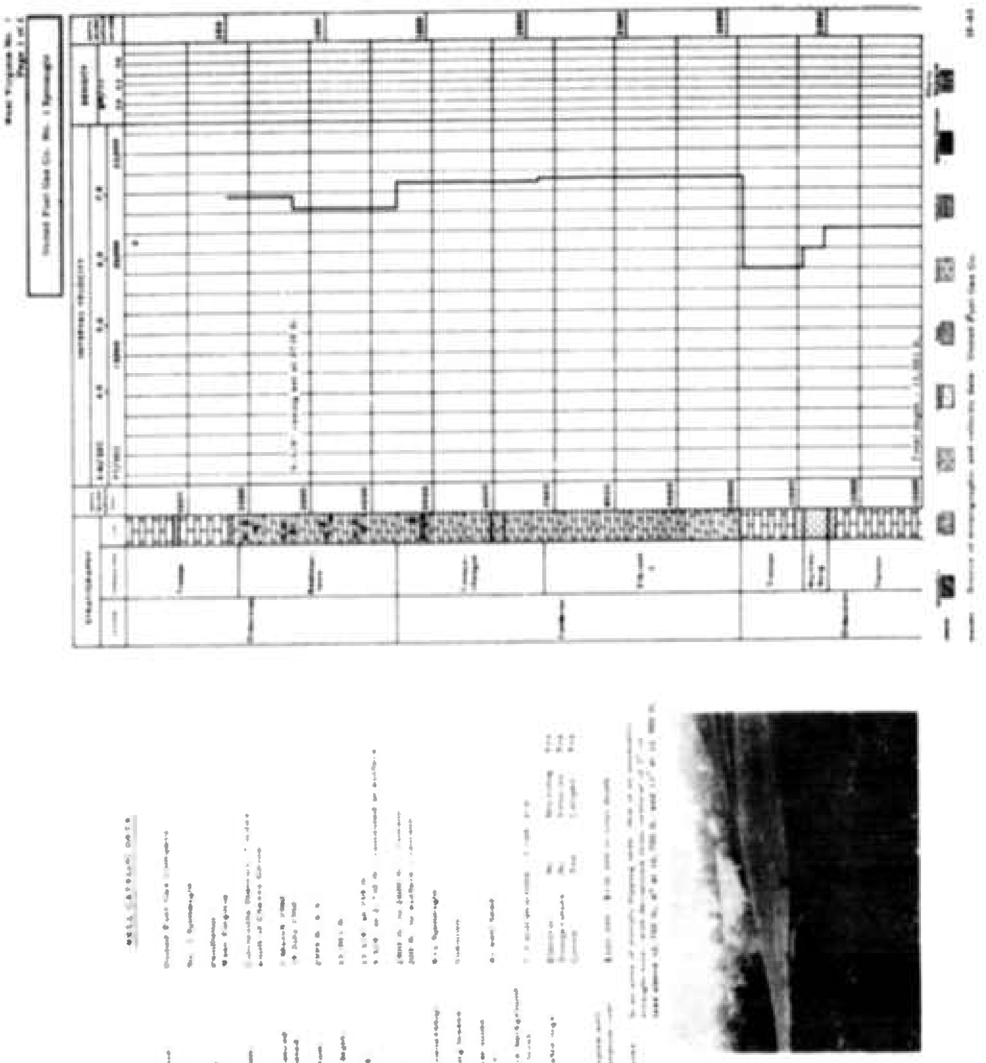


Figure 6. Well data, stratigraphy, velocity and density, well catalog

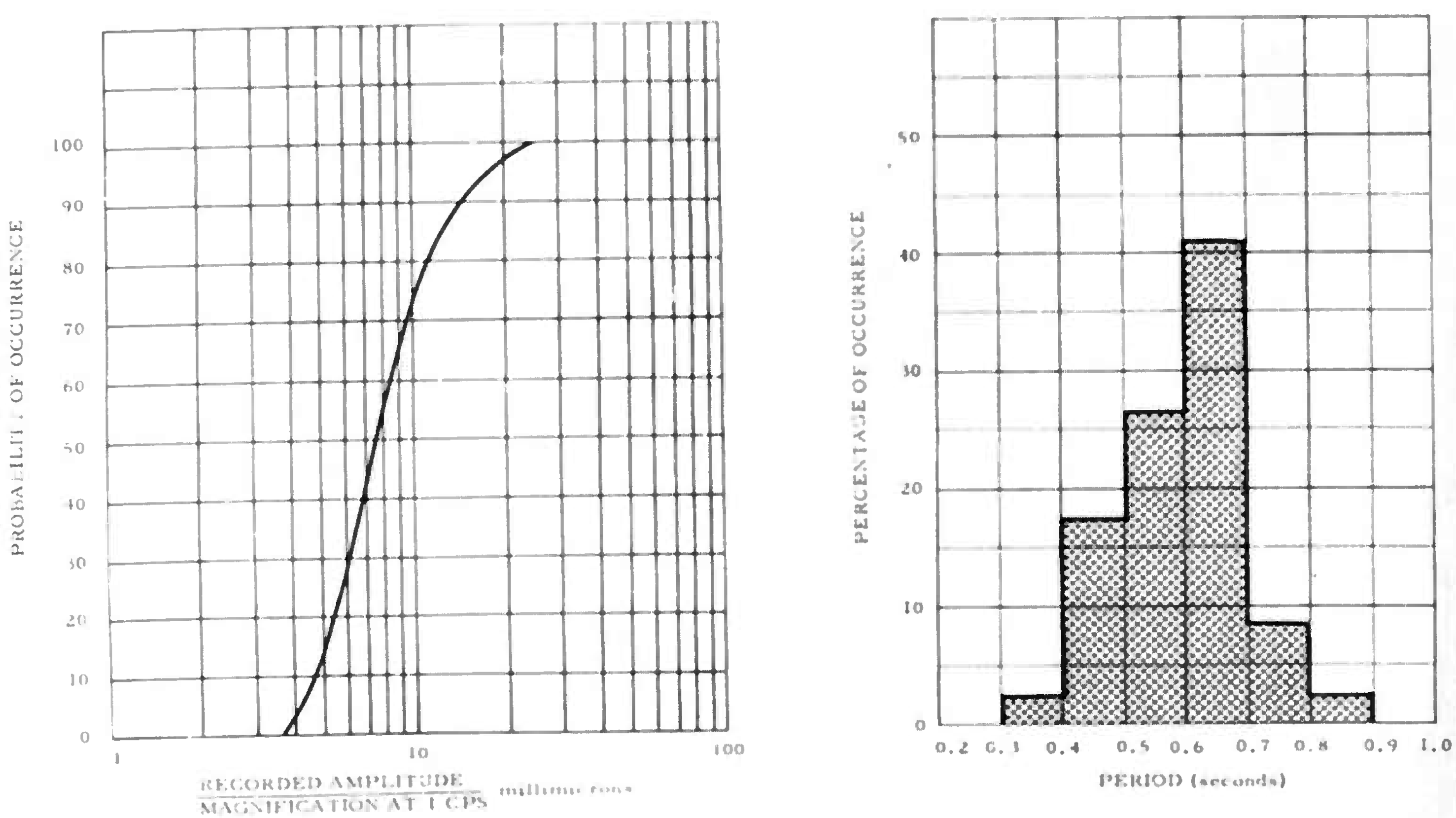


Figure 7. Surface noise data, well catalog

3.2 SITES PREPARED AND OCCUPIED

3.2.1 The Eniwetok E-1 well was cleaned out to its original total depth of 4,225 ft (1,290 m) and a 6-in.(15-cm) diam casing liner was set from 4,084 ft (1,245 m) to 4,210 ft (1,284 m) to provide a fully cased operating environment. Figure 8 is a diagram of the casing, cement, and liner in the well. The well preparation was completed, ready for field measurements on 17 June 1963. Figure 9 shows the completed well, and figure 10 is a map of the well site.

3.2.2 The Perdasofpy No. 1 well was re-entered, cased, and completed, ready for field measurements 18 June 1963. About 90% of the casing used in this well was salvaged from the Prater No. 1 well near Hobart, Oklahoma, which was prepared for field measurements in an earlier phase of Project VT/1139. The casing was cemented from top to bottom in the Perdasofpy well. Figure 11 is a diagram of the casing and cement. Figure 12 is a map of the well site. Figure 13 shows the velocity profile from sonic log values obtained during well preparation.

3.2.3 The Meridian Unit No. 1 well was re-entered, cased, and completed, ready for field measurements 11 July 1963. A fully cemented string of casing was not achieved in this well, as shown by figure 14, a diagram of the casing and cement. Figure 15 shows the well head just after the drilling rig was removed. Because of the well's remote location, the installation of commercial electric power facilities was not feasible, as illustrated by figure 16, a map of the well site. Figure 17 gives the velocity and density profiles from sonic and density log values obtained during well preparation.

3.2.4 Subsurface noise measurements were conducted in the Perdasofpy No. 1 and Meridian Unit No. 1 wells prior to the arrival of field measurement teams at these sites. The data obtained from these measurements were useful in the routine field measurements in these wells. Figure 18 shows the subsurface noise measurement equipment in operation at each of the wells.

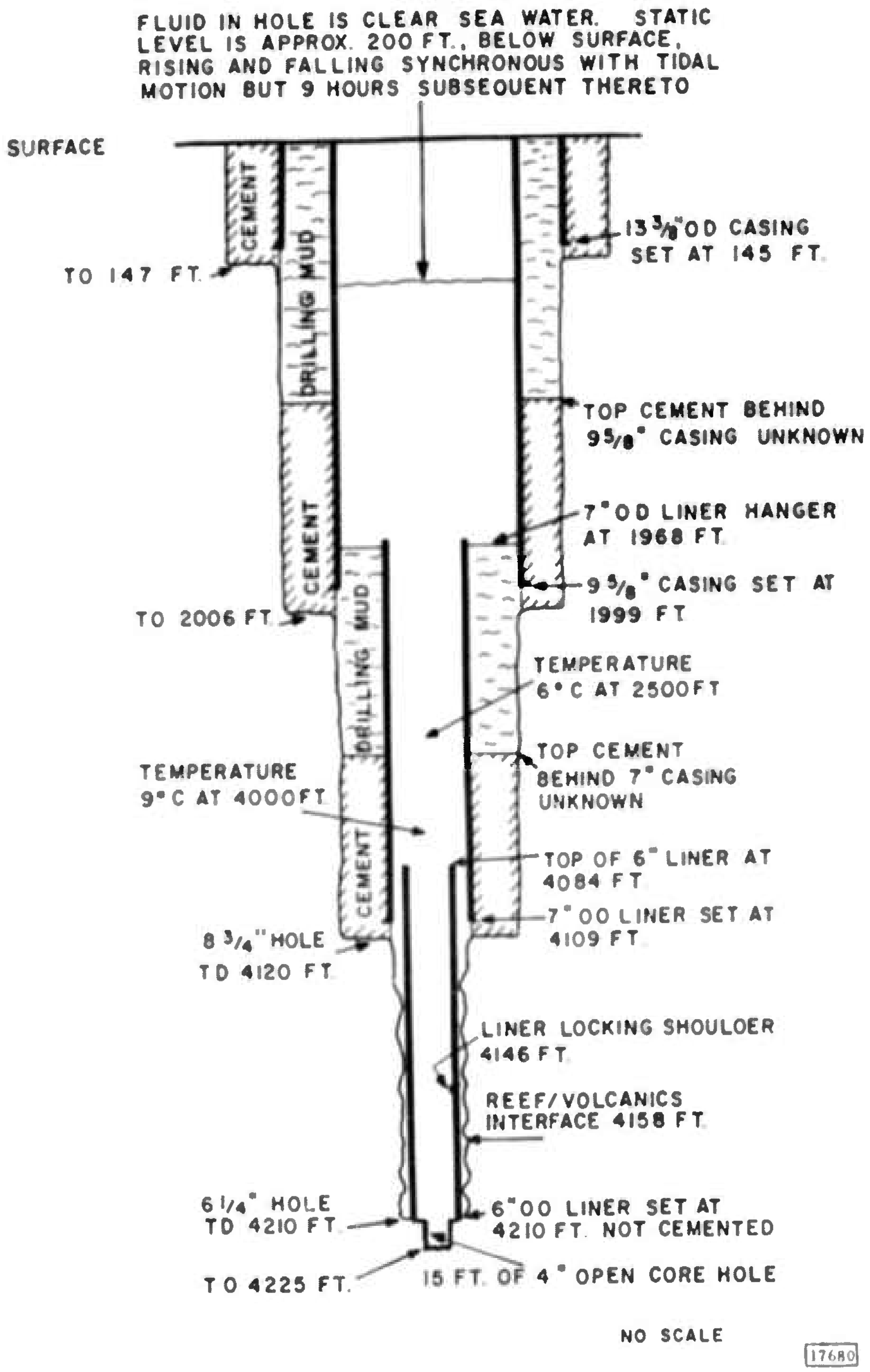


Figure 8. Casing diagram, Eniwetok E-1

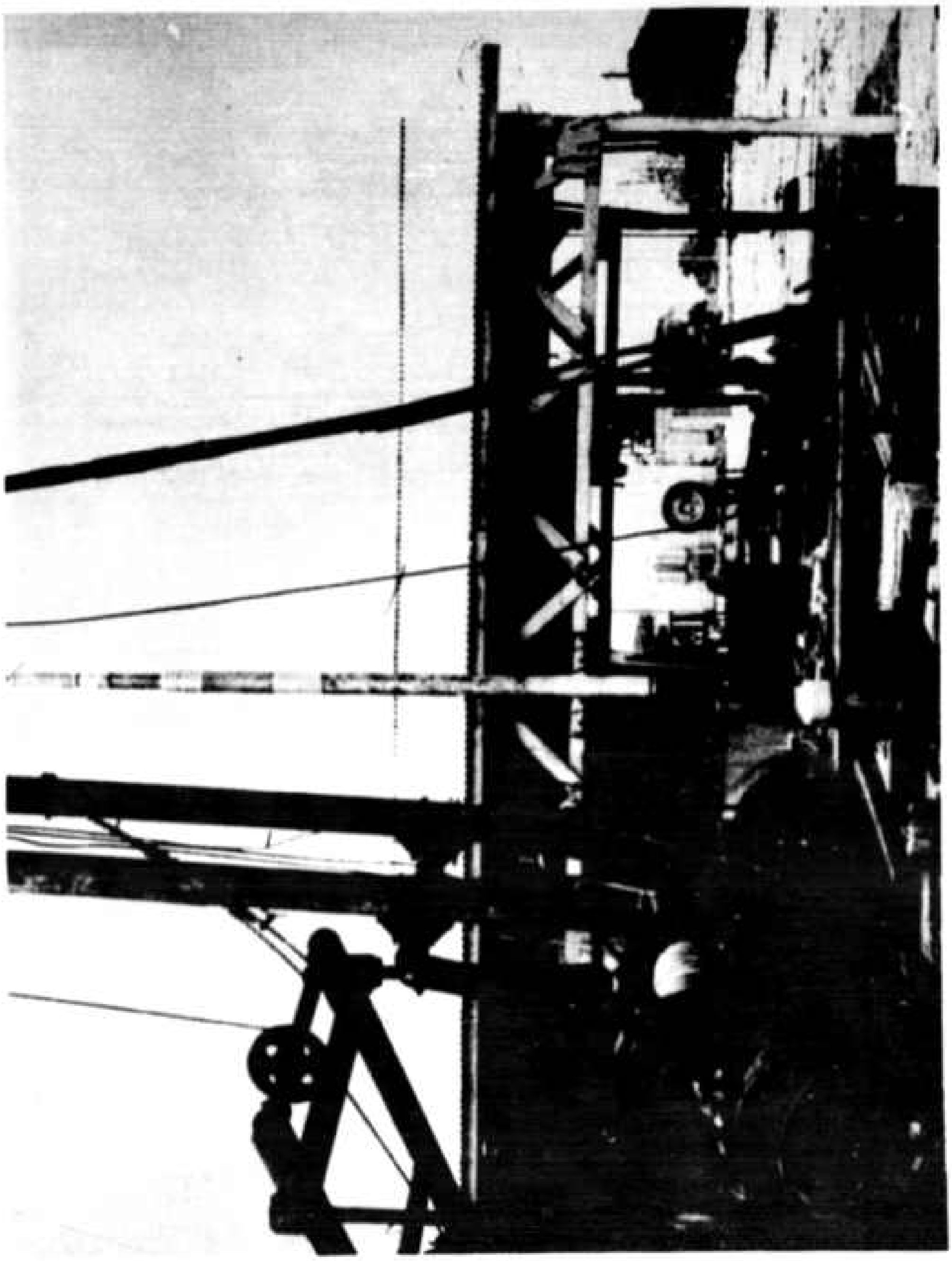


Figure 9. Completed well, Eniwetok E-1

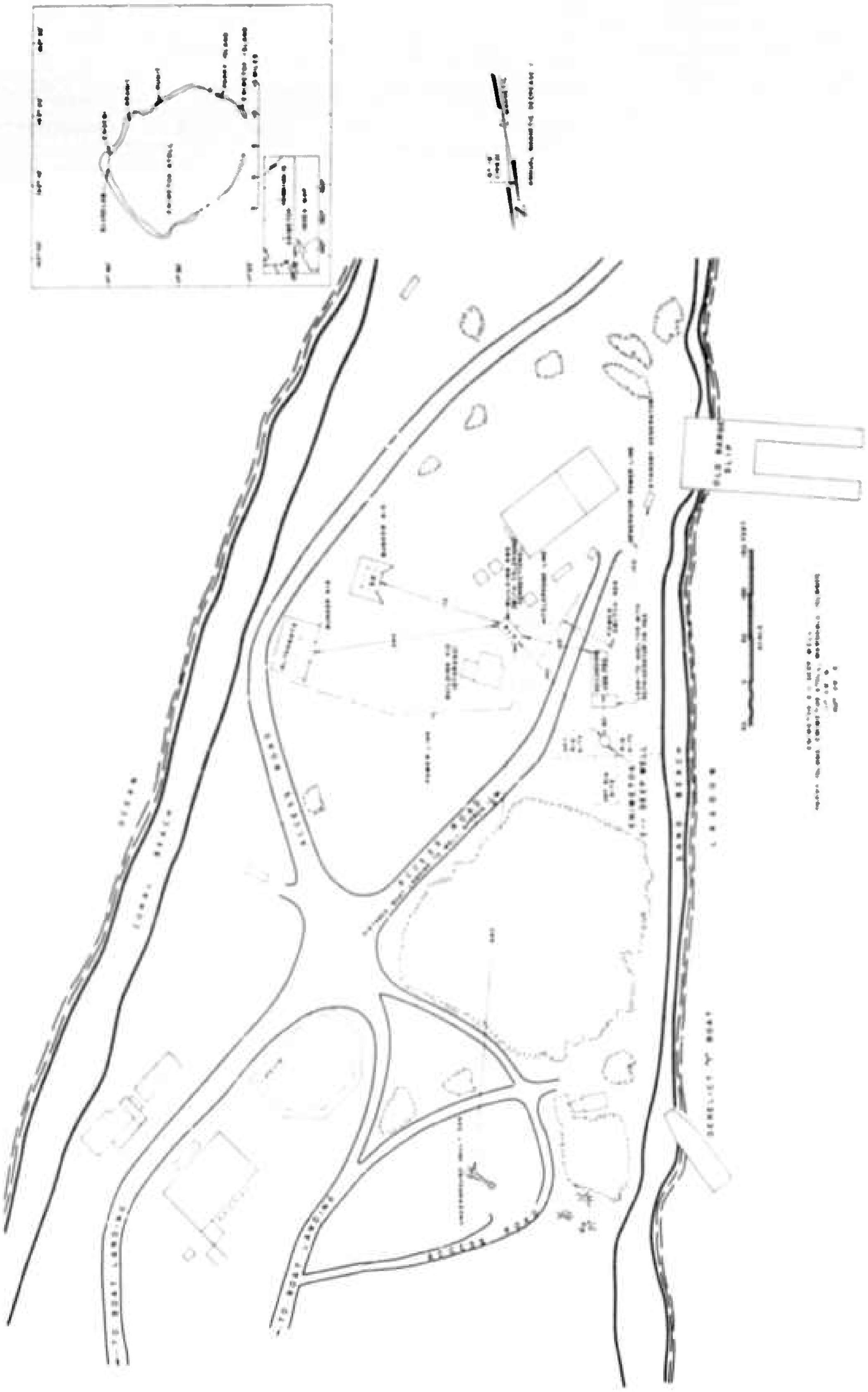


Figure 10. Site map, Eniwetok E-1

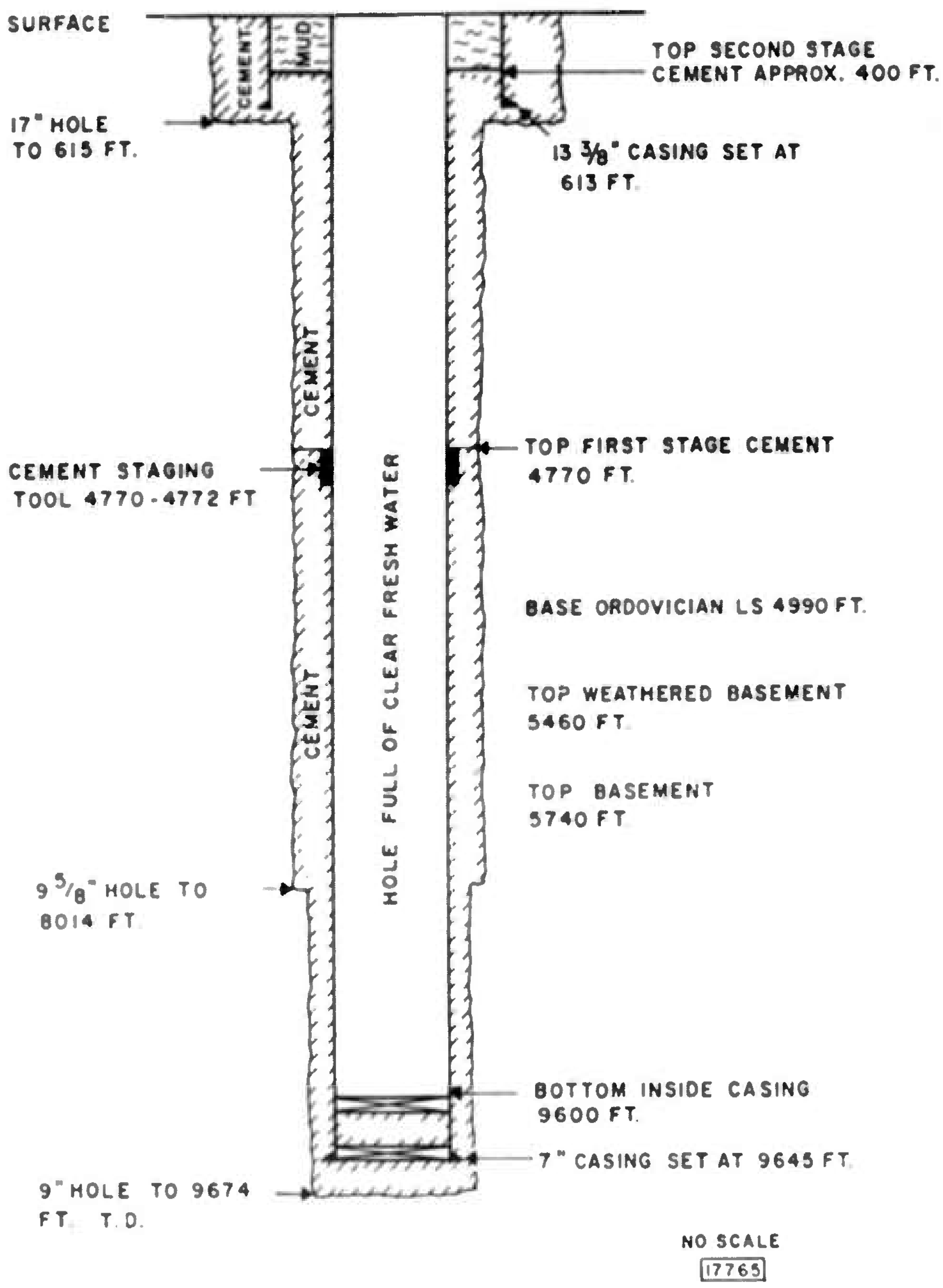
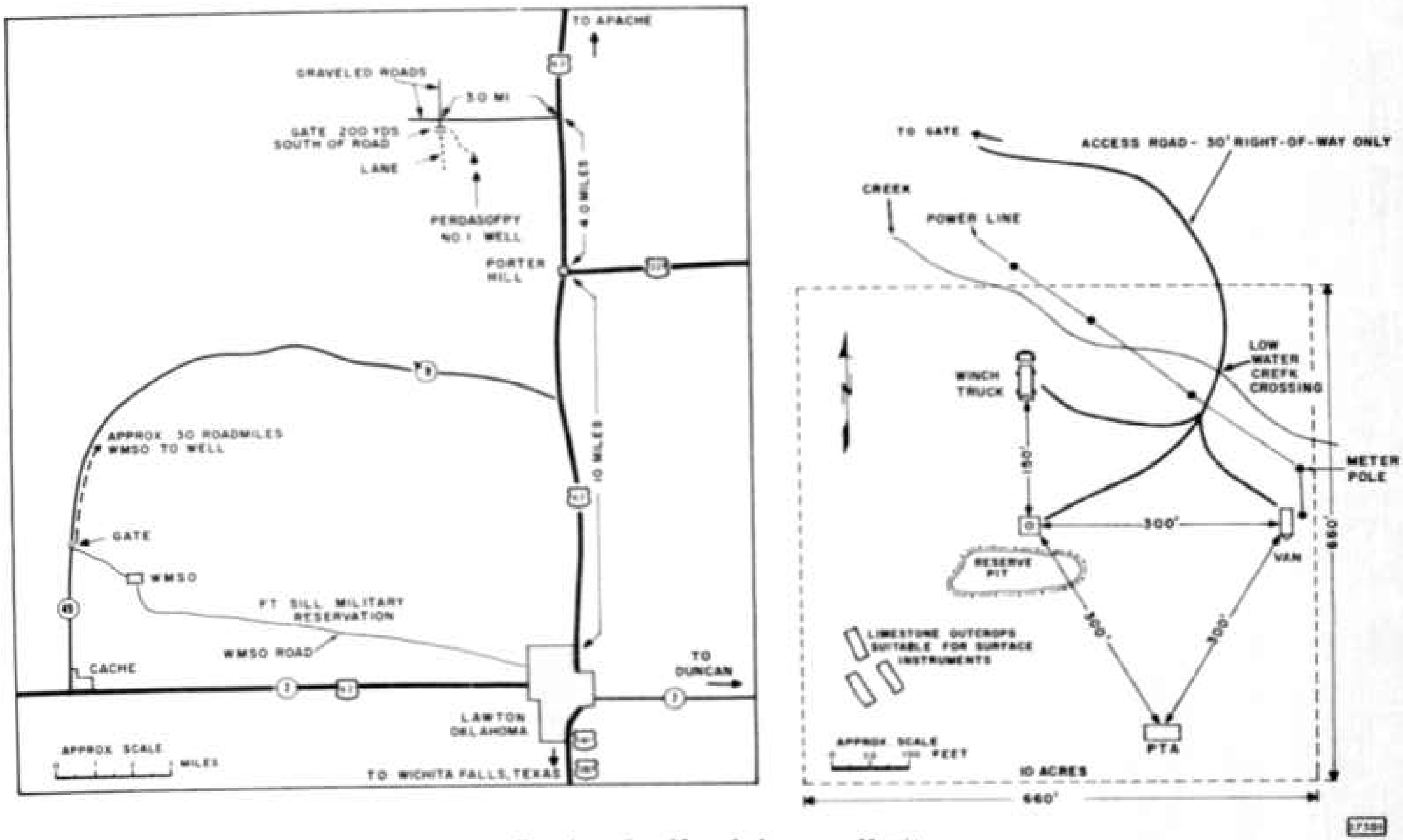


Figure 11. Casing diagram, Perdasofpy No. 1



Perdasofpy No. 1 deep-well site
Comanche County, Oklahoma
34° 49' 59'' N
98° 22' 21'' W

Figure 12. Site map, Perdasofpy No. 1

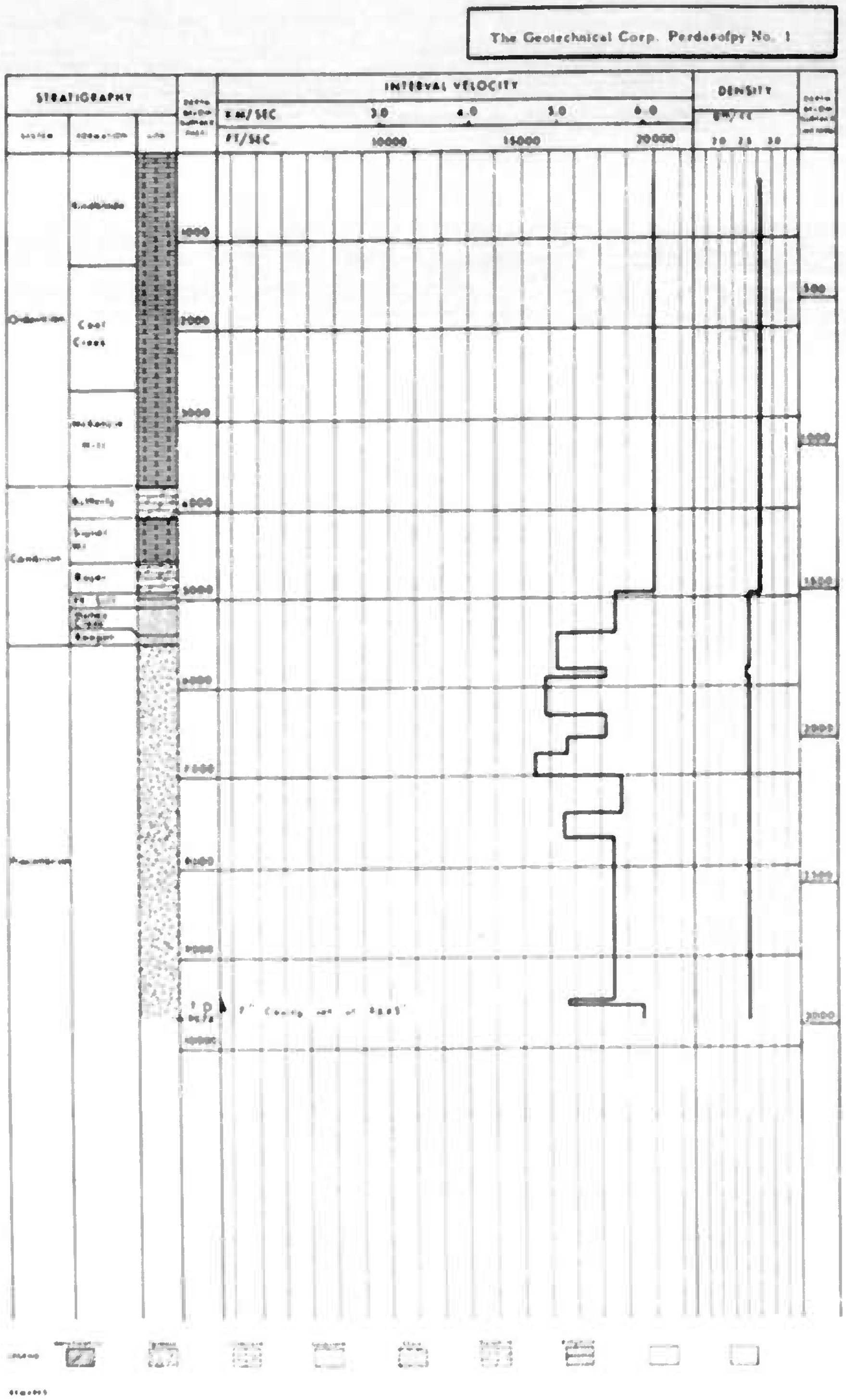


Figure 13. Geologic section, velocity and density, Perdasofpy No 1

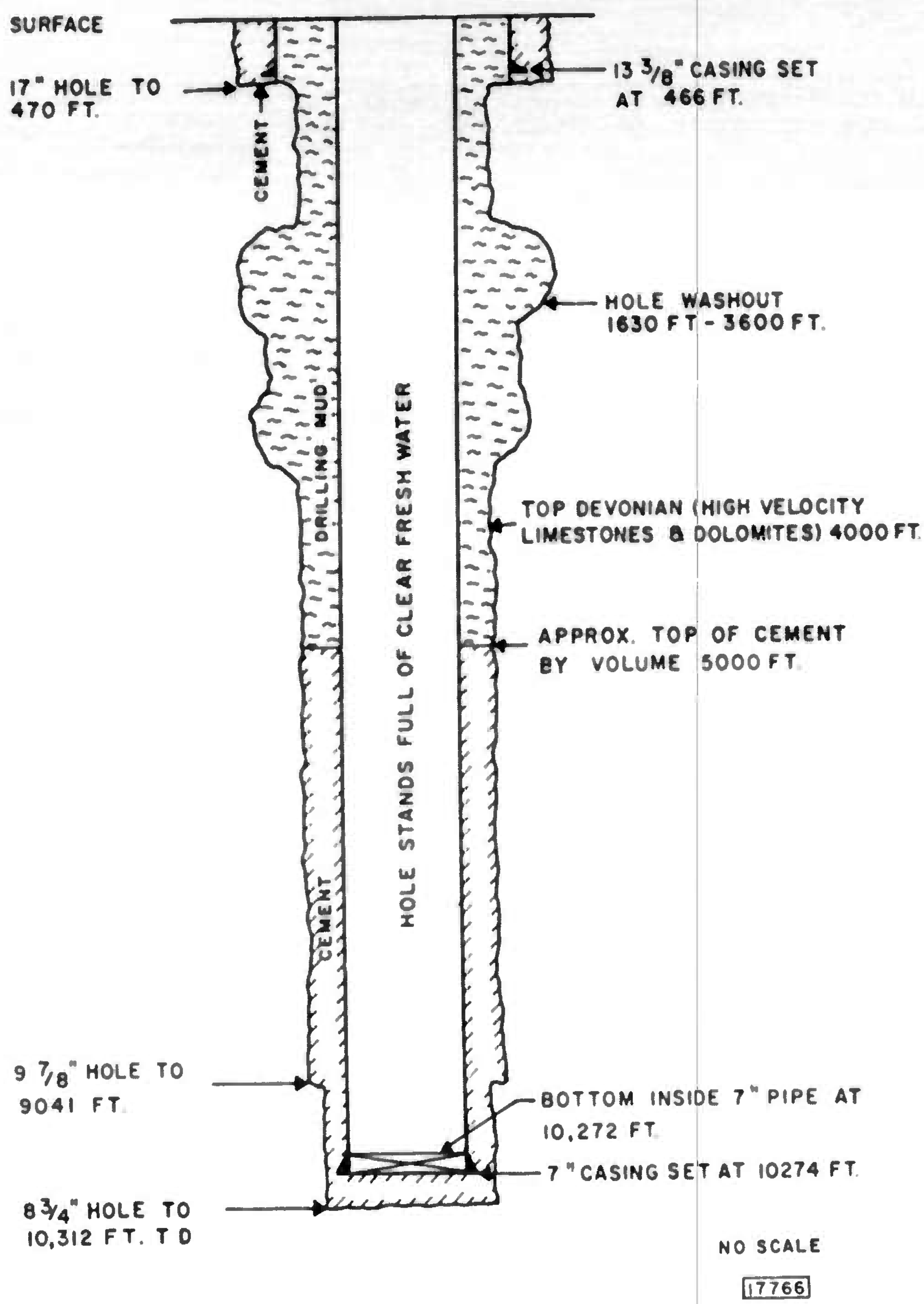


Figure 14. Casing diagram, Meridian Unit No. 1

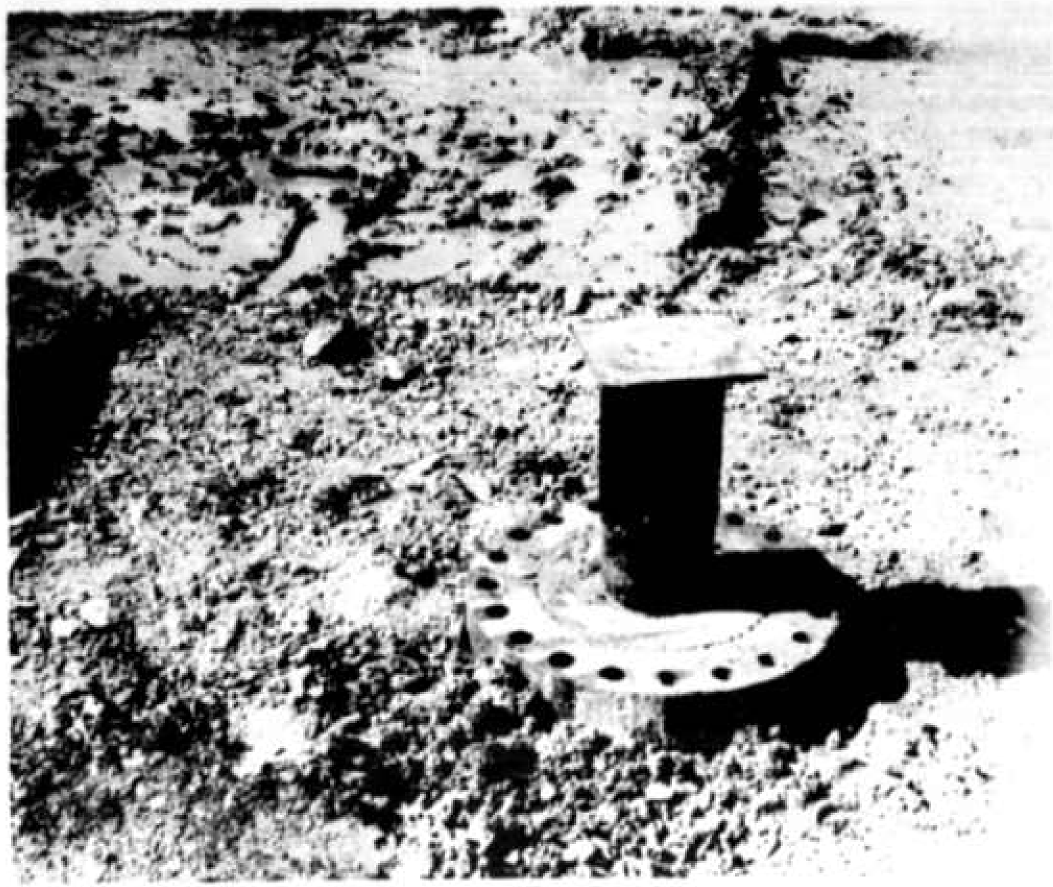
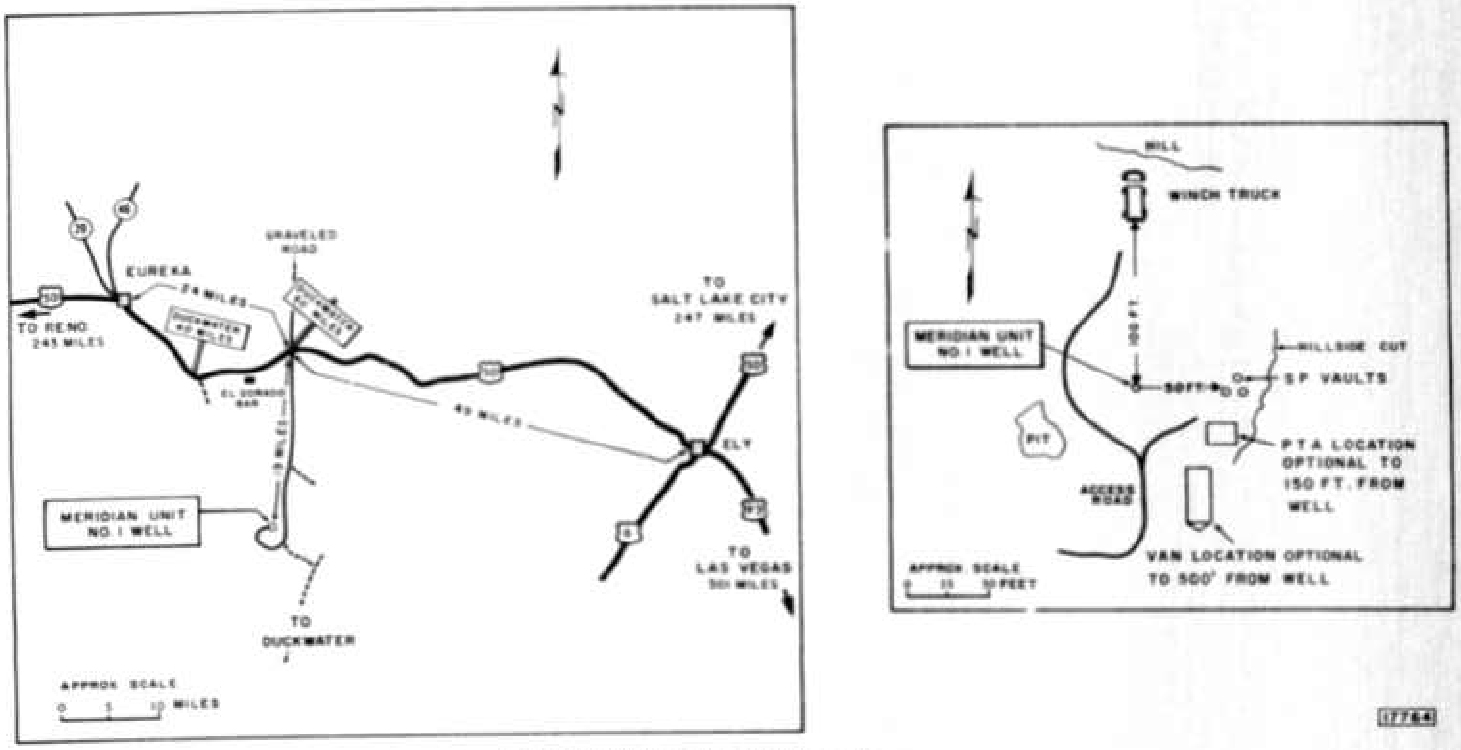


Figure 15. Well head, Meridian Unit No. 1



MERIDIAN UNIT NO I DEEP WELL SITE
WHITE PINE COUNTY, NEVADA

39° 12' 32" N
115° 42' 37" W

Figure 16. Site map, Meridian Unit No. 1

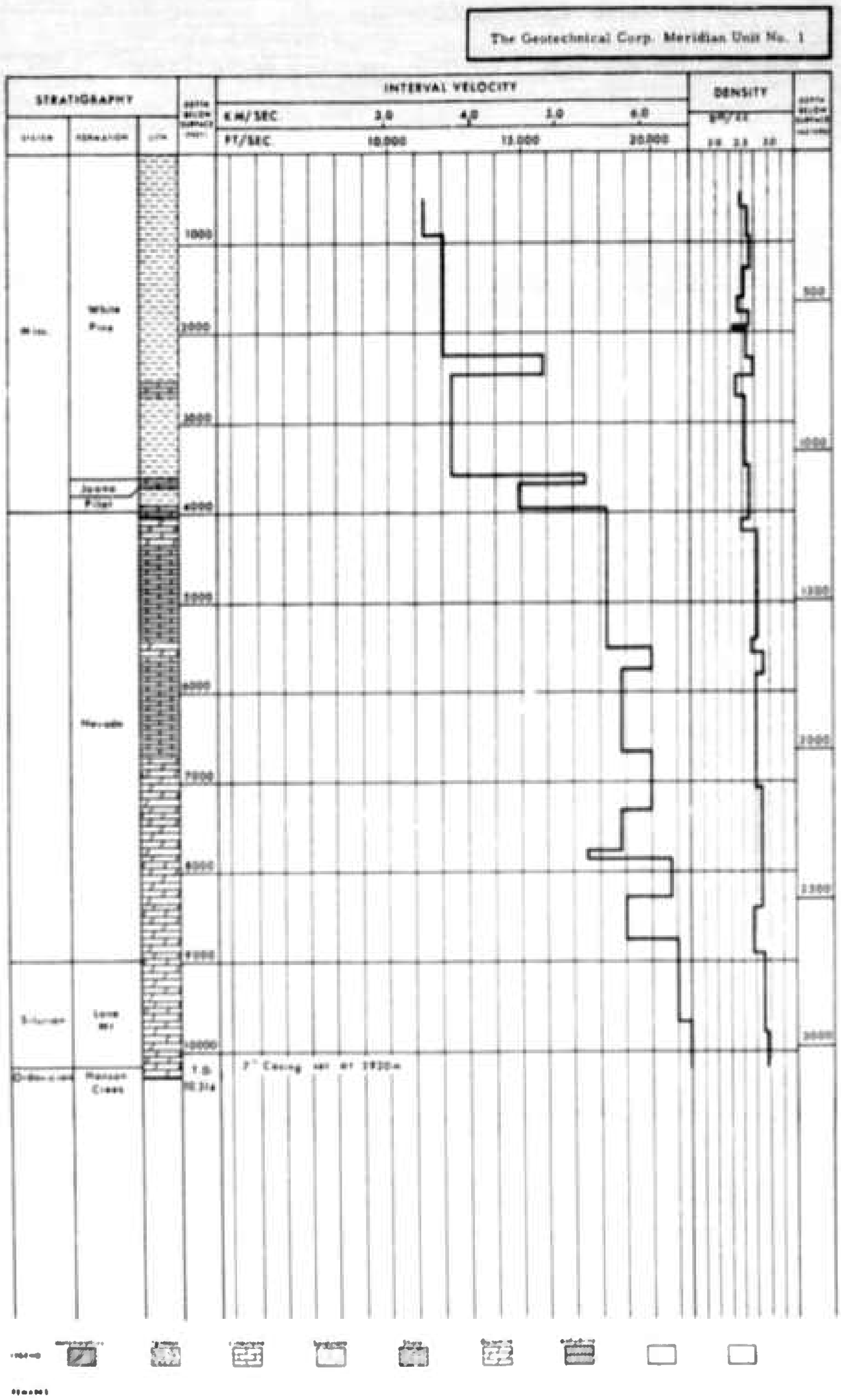
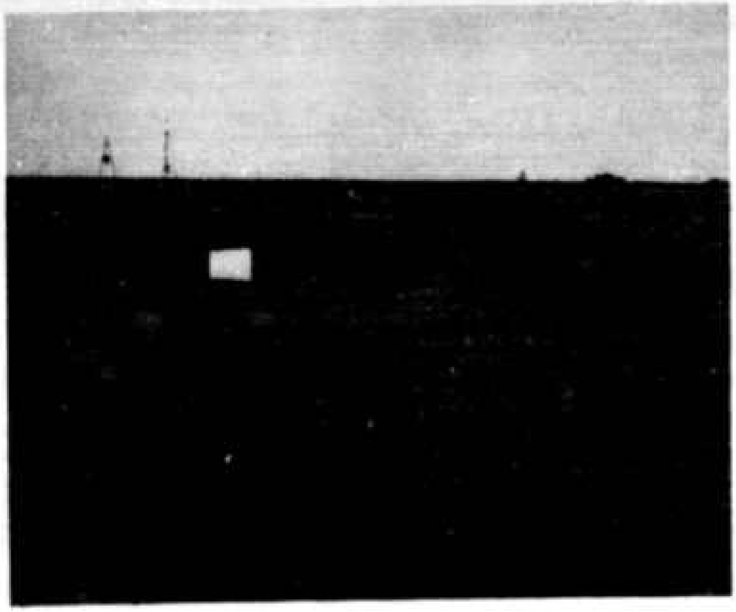


Figure 17. Geologic section, velocity and density, Meridian Unit No. 1



Perdasofpy No. 1 in Oklahoma

Meridian Unit No. 1 in Nevada

Figure 18. Subsurface noise measurements

4. CONDUCT FIELD MEASUREMENTS, TASK 1h (3)

Field measurements were made at three sites during the period covered by this report. A discussion of the data obtained appears in section 8 of this report.

4.1 The first deep-well site approved, located near Orlando, Florida, OR FL, was made operational and operated routinely from 12 May to 15 September. The seismometer was operated at depths of 2,000, 1,800, 1,520, 1,270, 1,060, 760, 450, and 152 meters.

4.2 The Eniwetok site, EW IS, was operational from 28 June to 15 September. The seismometer was operated at depths of 302, 586, 905, 1,262, and 1,284 meters.

4.3 The Oklahoma site, AP OK, near Apache became operational with the deep-well seismometer on 24 September, using the equipment and crew from the Florida well. At the time of this report, measurements had been made in the well at depths of 2,917, 2,584, 2,272, 1,960, 1,662, 1,356, and 1,044 meters. A second seismometer was placed in operation in an 18-m well on 21 October.

4.4 A preliminary survey of the Nevada site, near Eureka, EK NV, was made in August. The team and equipment from Eniwetok moved to this site near the end of October. Problems in the cable will delay operation of the deep-well seismometer until after the end of this reporting period.

4.5 Two winch trucks have been purchased and are being used at EK NV and AP OK. These trucks replaced leased Schlumberger trucks.

5. OPERATE AND IMPROVE GRAPEVINE SITE, TASK 1i (1) PERFORM EXPERIMENTS AT GRAPEVINE, TASK 1i (2)

5.1 New equipment and facilities at Grapevine include the following:

a. Two skid-mounted winches, shown in figure 19. The winches are used to operate two seismometers in a single well on independent cables.

b. An electric motor-powered winch has been installed on a concrete pad at the 153-m well.

c. A 1.8-m diameter by 6.1-m deep tank was installed vertically beneath the surface of the earth at the top of the 153-m well. As shown in figure 20, this tank provides a wind-sheltered enclosure which is useful for tests on seismometers.

d. A concrete foundation has been poured adjacent to the existing work building for construction of additional work space. The building, which will be 2.4 by 6.1 m, will be erected in December.

5.2 Dual seismometer operation on independent cables has been accomplished. Each seismometer has been moved in the well without disturbing the other. This type of operation is much more flexible and easier to accomplish than the clamped-cable type of operation, which was previously used.

5.3 Other work performed at Grapevine includes:

a. Evaluation of improvements to the seismometers, such as a weight-lift calibrator, modified calibration coil, and an improved mass locking device;

b. Operation of the seismometer in the silo to avoid extremes of weather;

c. Recording of events whenever such recording did not delay other experiments.

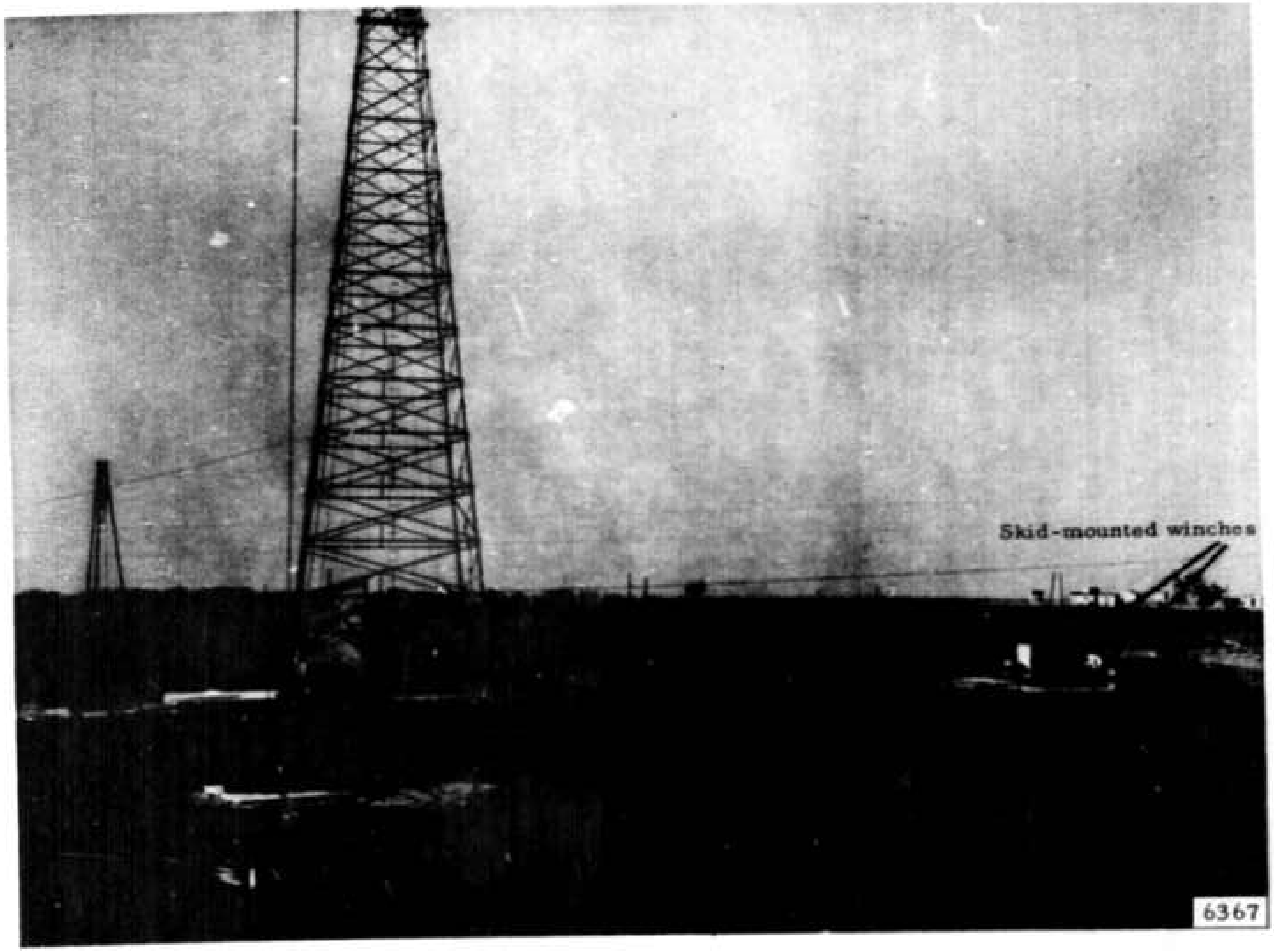


Figure 19. Skid winch units

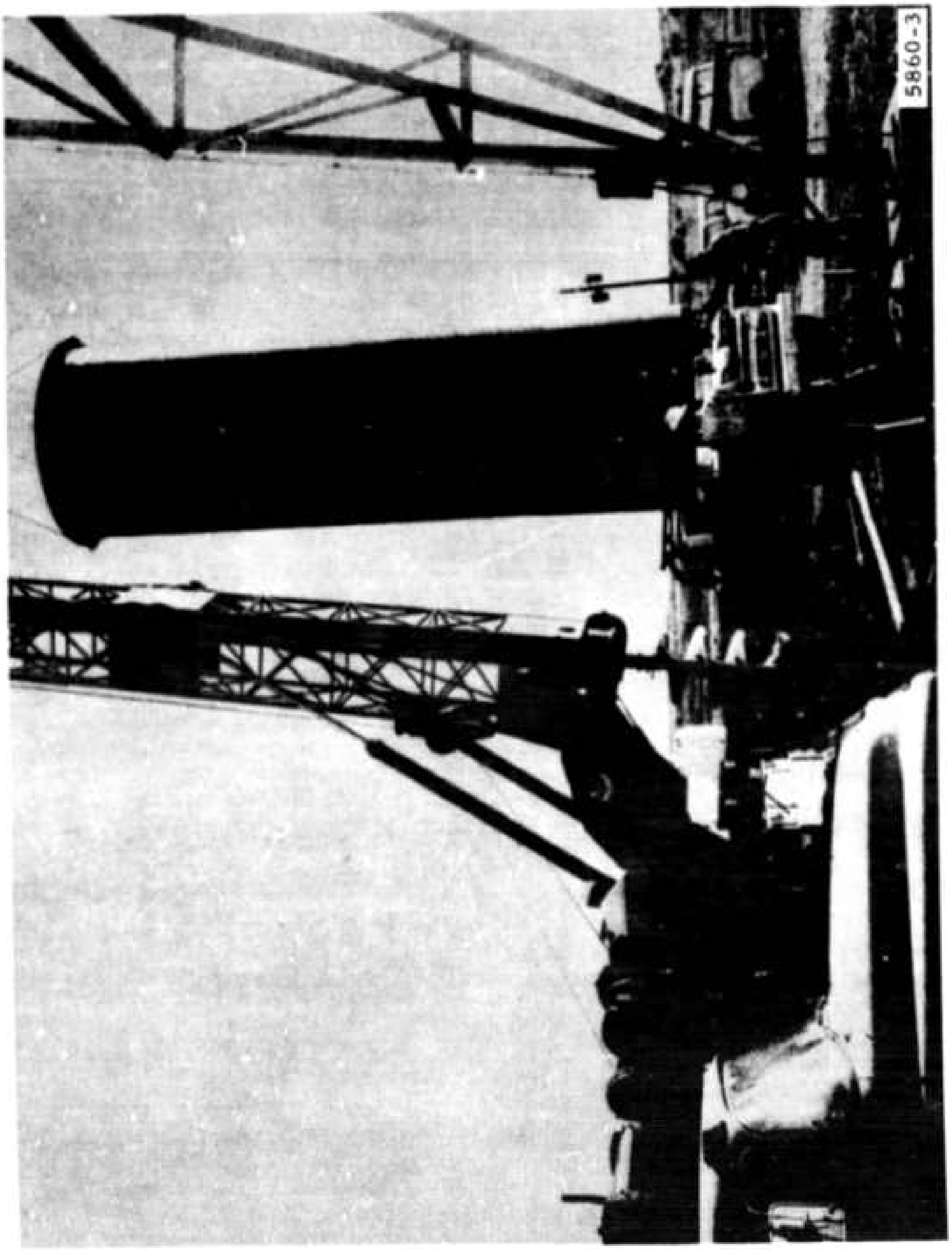


Figure 20. Subsurface tank

6. IMPROVE SEISMOGRAPH DESIGN, TASK 1i (3)

6.1 Several improvements to the seismometer were made during the period covered by this report. The improvements that have been incorporated into the seismometer are listed here with a brief description of each.

a. A threaded metal sleeve has been added to the lower end of the mass. It can be screwed down to hold the mass securely against the upper stop during shipment. For operation of the seismometer, the lock is loosened to release the mass and set the total mass travel.

b. A metal ring has been designed that can be easily attached to the bottom of the transducer to provide improved lateral support to the transducer in shipment.

c. A weight-lift calibrator, shown in figure 21, has been designed to give a known impulse to the seismometer mass. The calibrator consists of a solenoid, spring, and weight. When the solenoid is energized, a precise weight is added to the mass of the seismometer. When the solenoid is turned off, the spring quickly lifts the weight from the mass. A control unit at the surface of the ground gradually increases and then decreases the current to the solenoid. This slow change of current takes several seconds, thus minimizing cross-talk in the cable and undesired forces on the mass due to changing magnetic flux in the solenoid.

d. A lower limit switch has been added to the mass-centering motor to prevent overtravel of the lead screw.

6.1.1 Several improvements were not complete at the end of the reporting period. Some of these are:

a. Improvement of the electrodynamic calibrator;

b. Stronger, more reliable mass position contacts;

c. Redesigned transducer section to minimize the effects of pressure.

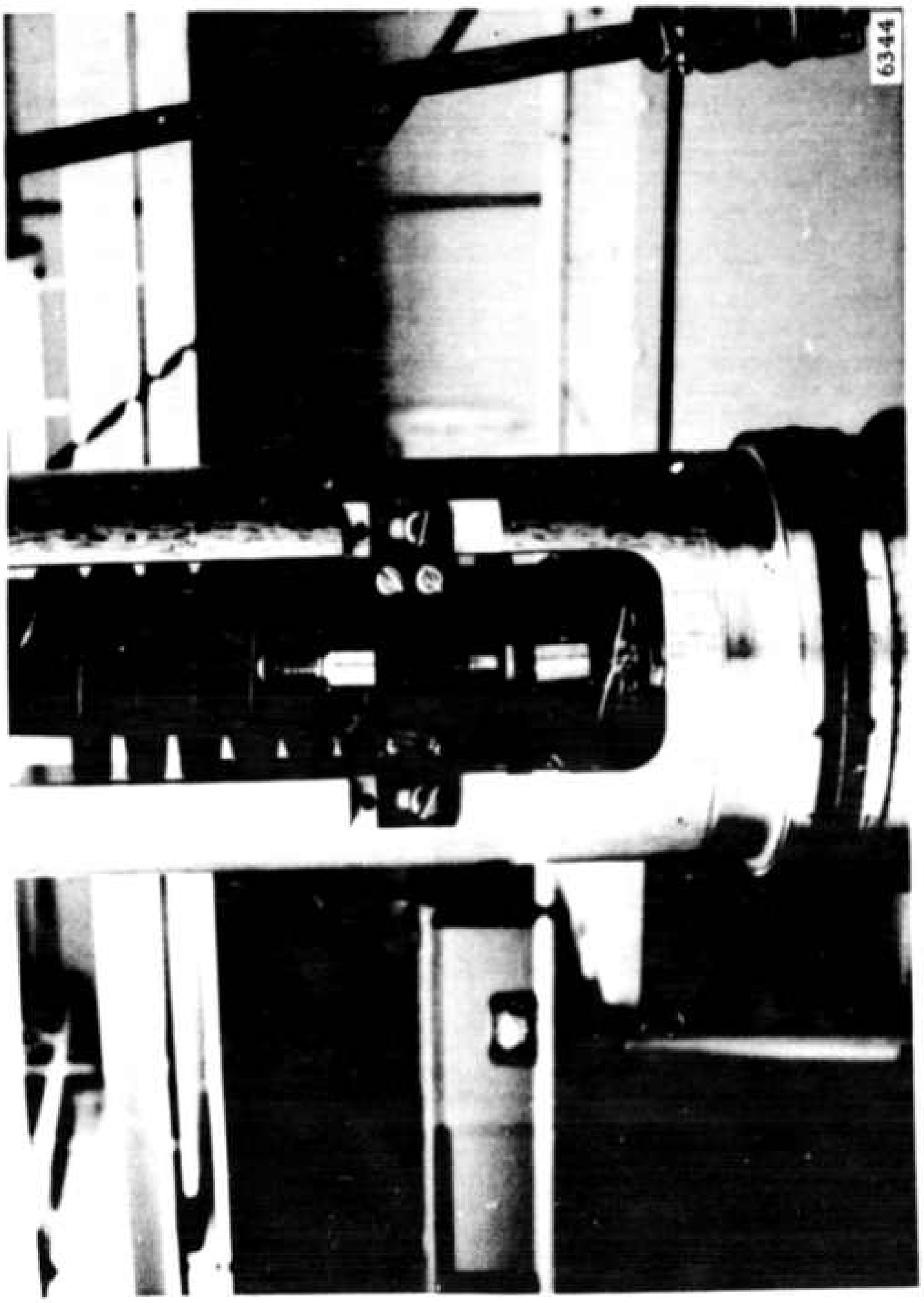


Figure 21. Weight-lift calibrator

6.2 A cam-type hole lock has been designed, as shown in figure 22. It is now being tested.

6.3 An operational amplifier unit is under development. This unit will give about an order of magnitude more magnification and will permit the recording of the sum or difference of two or more signals.

6.4 The deep-well seismograph, with a 1.0-sec seismometer and a 0.2-sec galvanometer in the phototube amplifier, has a response peaked at about 0.4 sec. In order to increase understanding of signals and noise at longer periods, it is desirable to peak the system at longer periods. An amplifying system using a Phototube Amplifier, Model 5240, with a 3.3-sec galvanometer and special filters has been assembled to enhance long-period signals. The response of the system is shown in figure 23. The system will be tested at the Grapevine site.

7. MAKE INSTALLATION NEAR A PERMANENT STATION, TASK 1j

7.1 SITE SELECTED AND DESIGNATED

Authorization was received from AFTAC on 22 October 1963 to proceed with the preparation of the U. S. A. No. 1 well near the Uinta Basin Seismological Observatory array at Vernal, Utah. Competitive bids for drilling rig re-entry work and casing were invited on 23 October, and re-entry contract was awarded to the low bidder on 29 October.

7.2 SITE PREPARATION

7.2.1 Drilling rig equipment was moved to the U. S. A. No. 1 deep-well site beginning 1 November. The well was re-entered, cased, and completed, ready for field measurements 16 November. Figure 24 is a diagram of the casing and cement. Figure 25 shows the completed well, and figure 26 is a map of the well site.

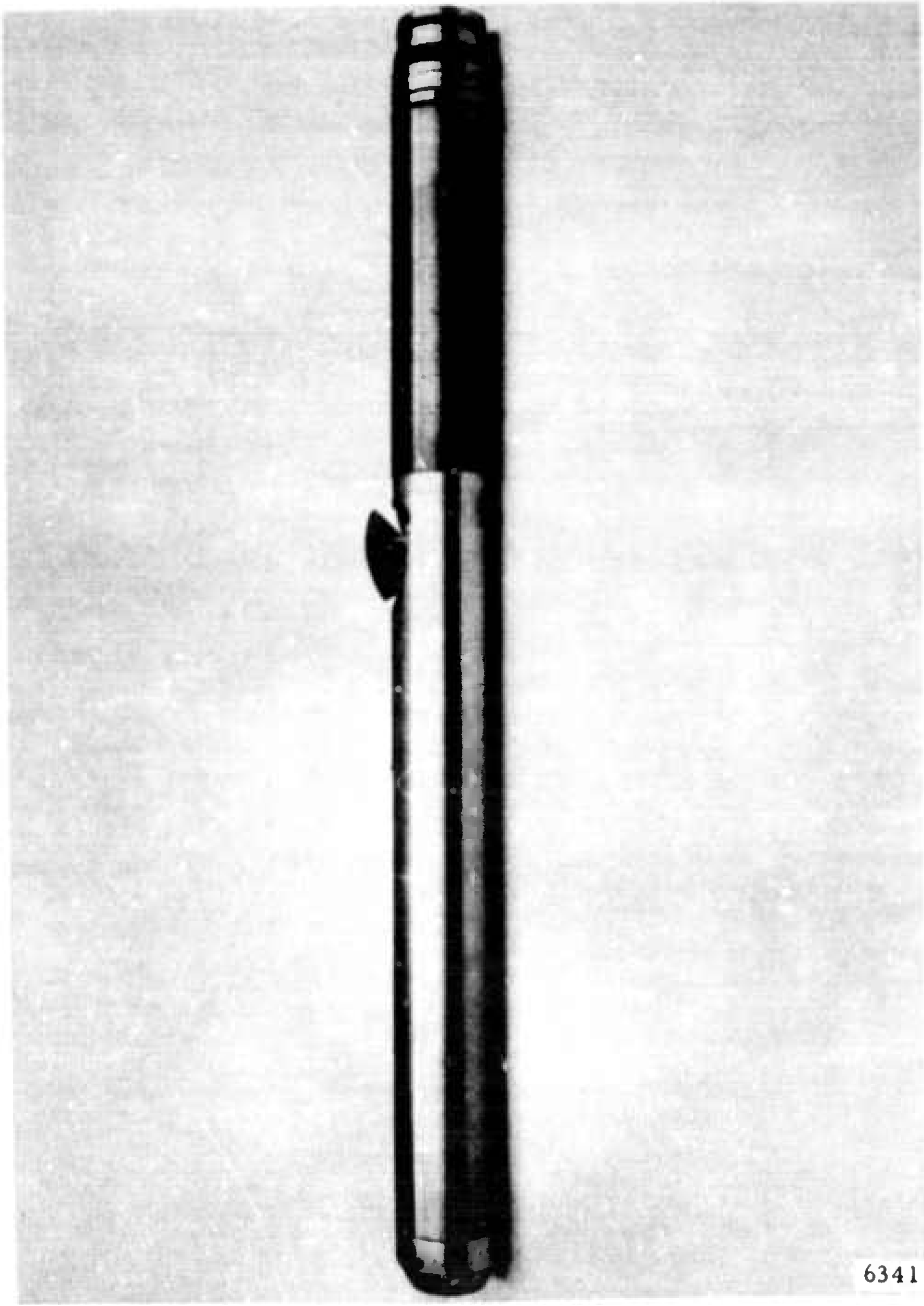


Figure 22. Cam-type hole lock

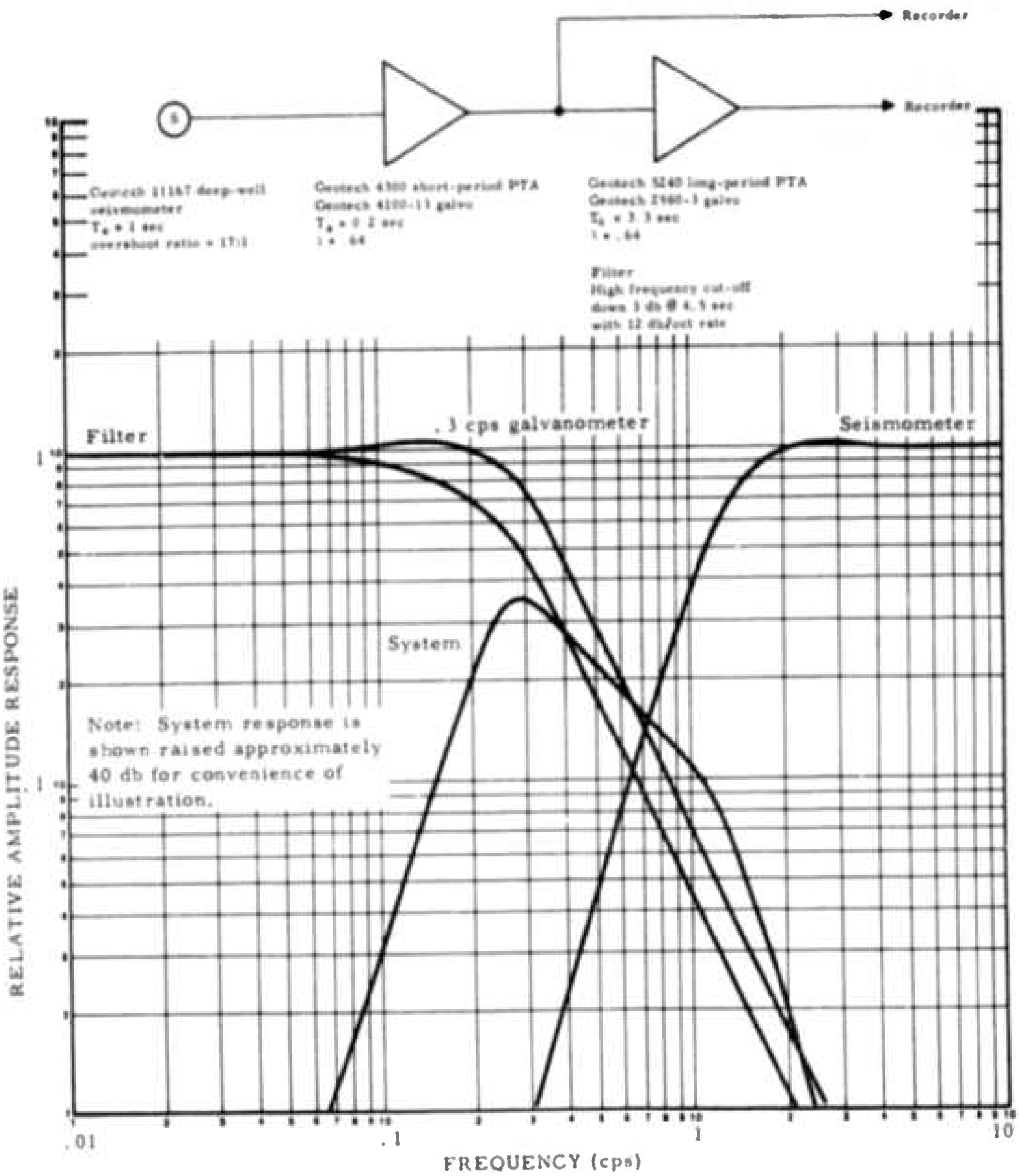


Figure 23. Theoretical response of deep-well seismograph with long-period galvanometer and filter

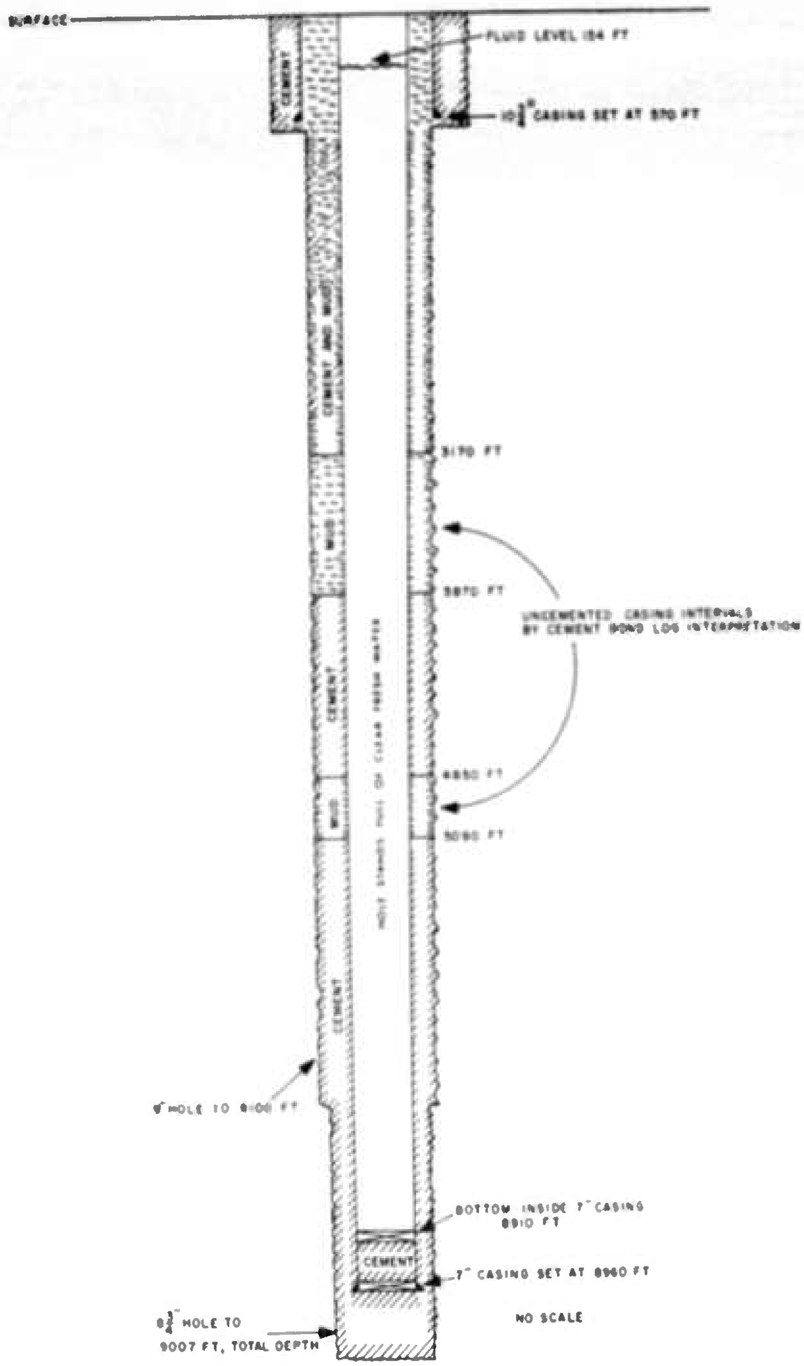


Figure 24. Casing diagram, U. S. A. No. 1

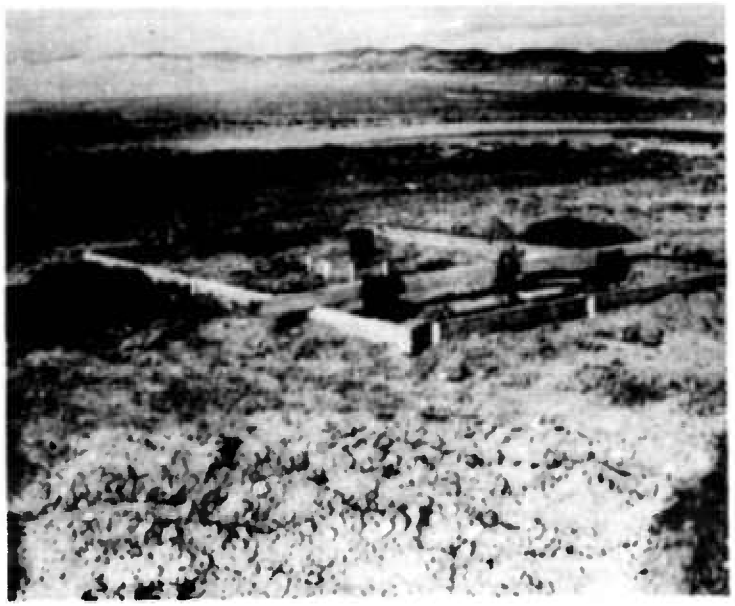


Figure 25. Completed well with forms set for pouring tripod pad, U. S. A. No. 1

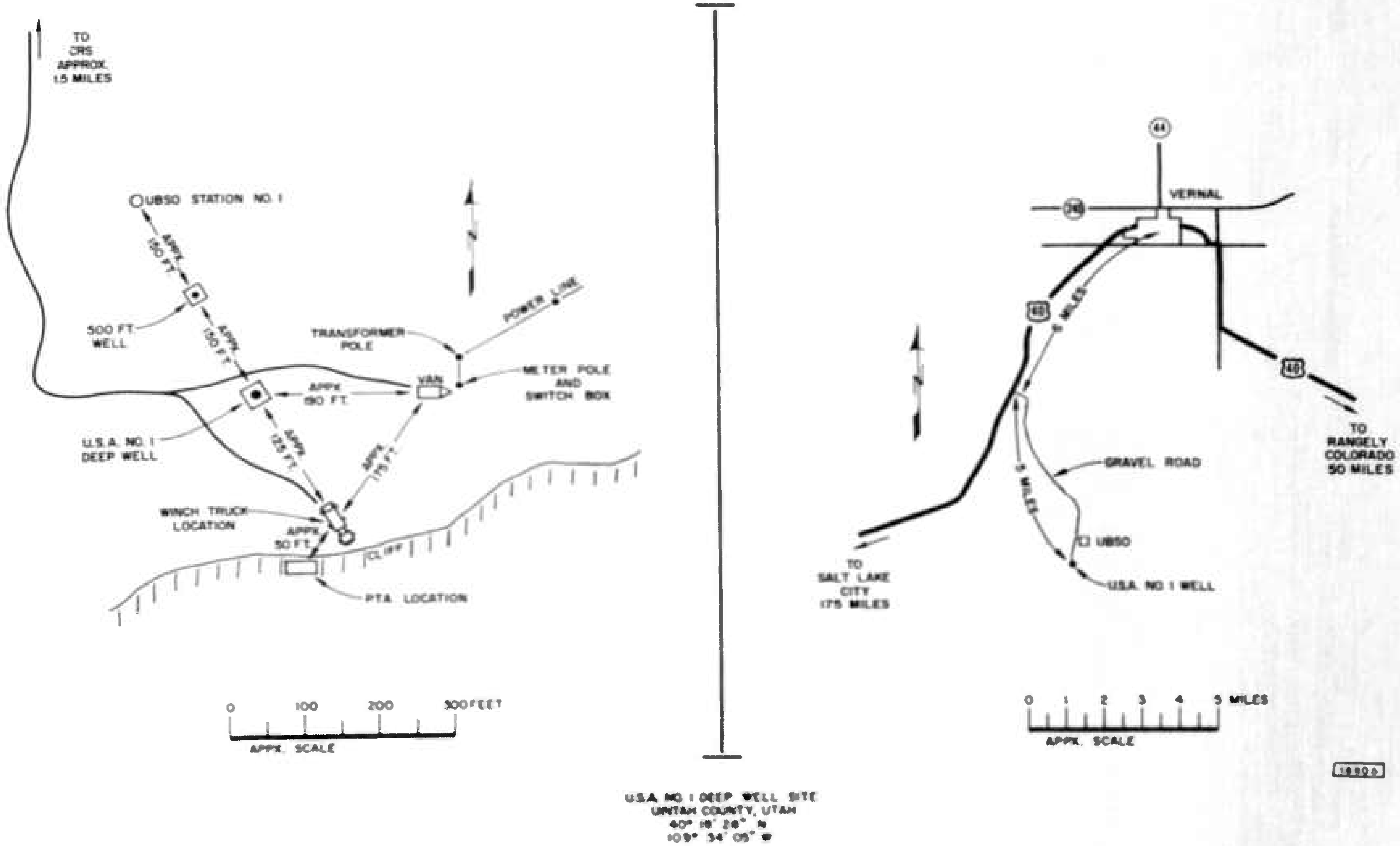


Figure 26. Site map, U. S. A. No. 1

7.2.2 Negotiations were completed on 12 November for the extension of commercial power facilities to the well site. Installation of these facilities was completed on 22 November.

7.3 INSTALLATION OF EQUIPMENT AND INSTRUMENTATION

At the close of the reporting period, equipment and instrumentation were being assembled and plans were being completed for the necessary installation to link this deep-well seismograph to the permanent UBSO system. Equipment and crew are scheduled to occupy this site near the end of the year.

8. PROCESS DATA, PERFORM DETAILED ANALYSIS, TASK 1k

8.1 METHOD OF MEASURING NOISE

The noise distribution curves given in this report were obtained from Develocorder records by visually measuring the largest noise amplitude present in the 10-sec interval immediately following a 5-min mark.

The amplitudes, measured peak-to-peak, were not corrected for system response, and the magnifications at 1 cps were used to obtain the millimicron (mμ) values given. One hundred samples were taken at each depth during times when cultural activity was minimum.

The results are given as "probability of occurrence" curves which show the probability that a noise pulse of the same amplitude as a signal will occur at the same time. The slope of the curve gives a measure of the variability of the noise amplitudes.

The periods of the pulses measured are also plotted to allow a comparison of the periods predominant at each depth.

The method used has the advantage of ease of measurement and gives consistent, reproducible results by visual analysis; however, it should not be taken as a substitute for spectral analysis of the noise.

The probability of occurrence curves gives a good picture of the decrease in noise level in the deep well without making any attempt to distinguish between the attenuation of the different frequencies which occur in the noise.

To illustrate the decrease of the noise with depth, the 50% levels of the probability of occurrence curves are plotted against depth. Figure 27 shows the decrease of the noise in the wells investigated to date.

8.2 DATA ANALYSIS, FLORIDA (OR FL)

The analysis of the results obtained at Orlando, Florida, is discussed in detail in appendix 1. Spectral analyses of noise samples from various depths are presently being run by the Data Analysis and Technique Development Center (DATAC). The results of these analyses will be reported soon.

8.3 DATA ANALYSIS, ENIWETOK (EW IS)

The well at Eniwetok, Marshall Islands, reaches a total depth of 1,284 m and penetrates the basement. The section is composed of limestone with an average velocity of 3,048 m/sec, and the basement consists of high-velocity basalt.

Because of proximity to the ocean, the noise background is extremely large with a value of 280 mμ at the surface.

The well is cemented at 1,280 m and 580 m, and at these depths, coupling between the ground and the seismometer should be good.

The site presents several problems not usually encountered:

a. The theoretical decrease of Rayleigh waves may be in error because the velocity section is not accurately known. The ocean bottom slopes (up to 20 deg) away from the island to a distance of several kilometers; therefore, the plane-parallel layering assumption is violated.

b. The shallow depth of the well and the possibility of poor coupling at all depths except 1,280 m and 580 m increase the difficulty of studying the noise.

c. Few signals were recorded because of the high noise level.

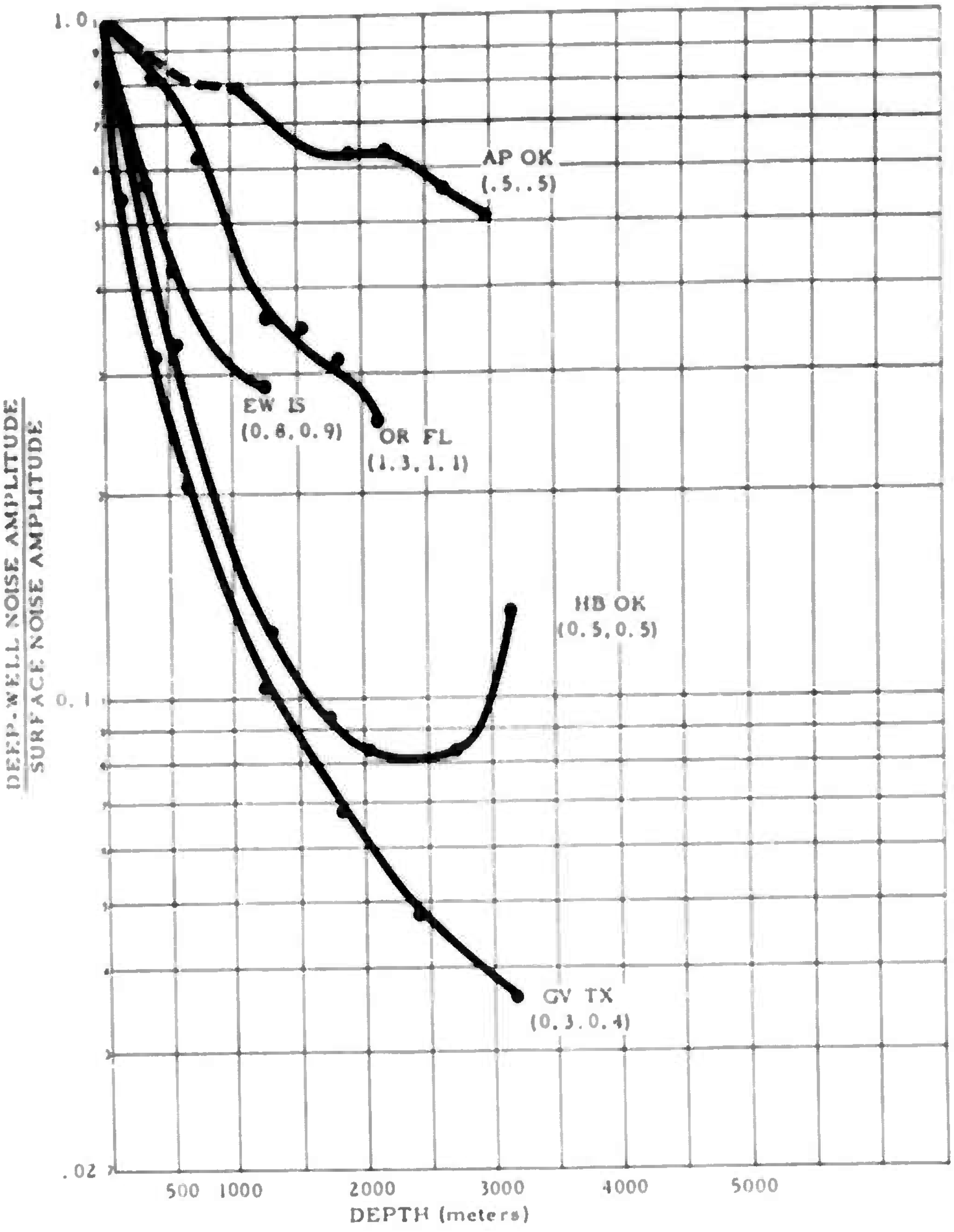


Figure 27. Noise decrease with depth, with various depths normalized to surface. Following site designators, the predominant noise period at the surface and at the bottom of the well are given.

8.3.1 Noise Analysis

The noise level at Eniwetok is very high, and decreases slowly with depth, as shown by the probability of occurrence curves of figures 28 through 31. These figures also show that the predominant period of the noise (0.8-0.9 sec) does not appreciably change with depth. High-frequency (2-4 cps) noise, common at almost all continental sites, is never observed at this locality.

The source of the noise microseisms is expected to be quite close to the island. The ocean depth increases rapidly (slope of approximately 20 deg) away from the island.

Figure 32 shows the 50% probability of occurrence levels of the noise plotted against the depth. Also shown is the theoretical decrease of the vertical component of fundamental and first higher mode Rayleigh waves with depth. The agreement between the two curves is poor; several explanations for the disagreement are possible:

a. The theory is not correct.

b. The noise does not consist of Rayleigh waves.

c. The noise consists of a mixture of Rayleigh waves and other types of wave motion (e.g., body waves).

8.3.2 Signal Analysis

In attempting to determine the signal-to-noise improvement obtained at depth in deep wells, the decrease of P-wave signal amplitude with depth must be examined as well as the decrease in the noise amplitude.

At the Eniwetok site, eight teleseismic signals were recorded with sufficient amplitude to be used for analysis. The P-wave amplitudes were measured from the first cycle at both surface and depth to avoid the interference caused by the surface reflections.

Figure 33 shows the decrease in signal amplitude with depth. The individual data points show very little scatter except at the depth where there is no cement behind the casing. Other sites investigated (Semiannual Report No. 4, Project VT/1139) show considerable scatter; the comparatively simple velocity section at Eniwetok is probably responsible for the consistent results.

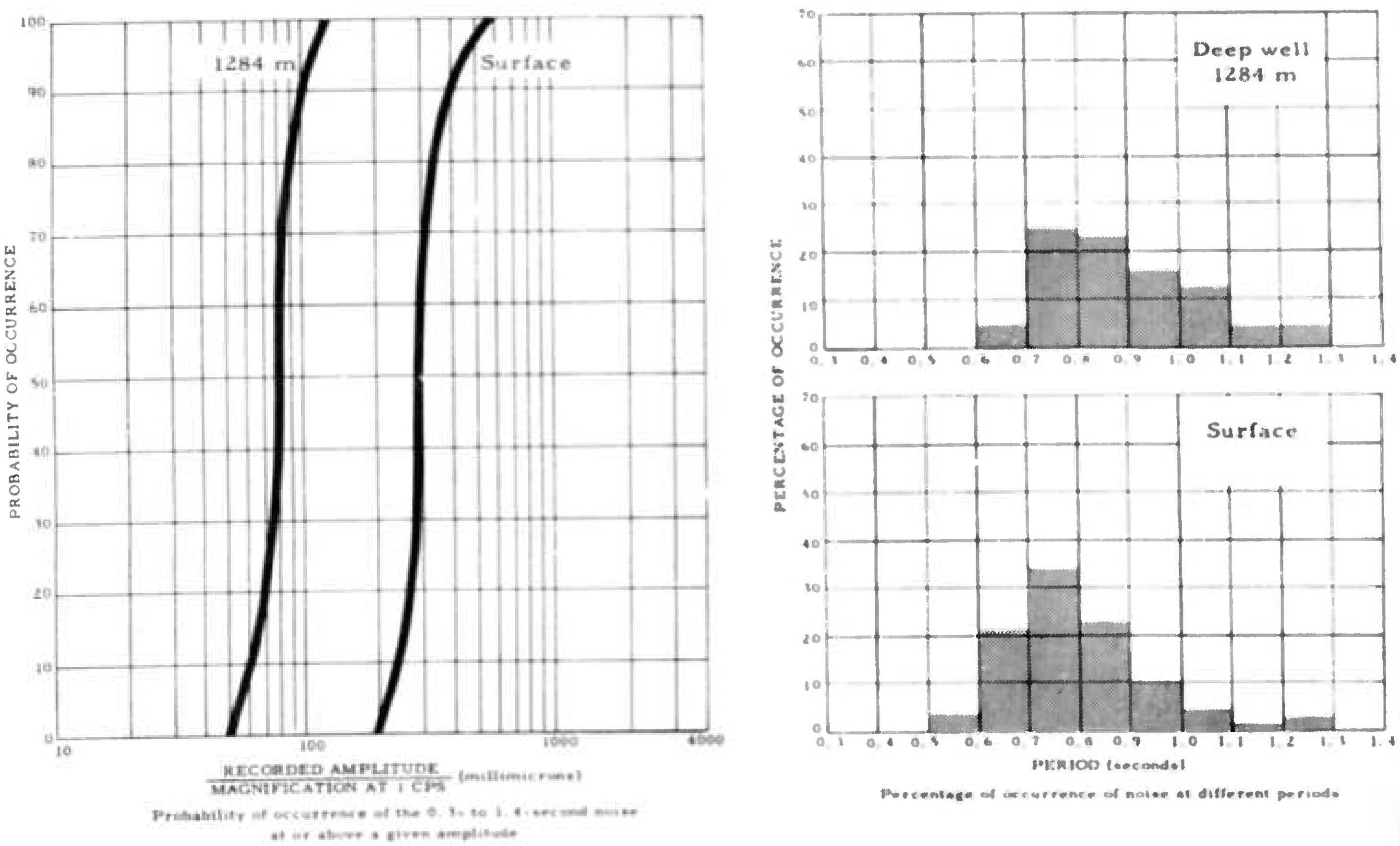


Figure 28. Probability of occurrence and percentage of occurrence of the 0.3-1.4 sec noise at the surface and in the deep well at 1284 m at Eniwetok

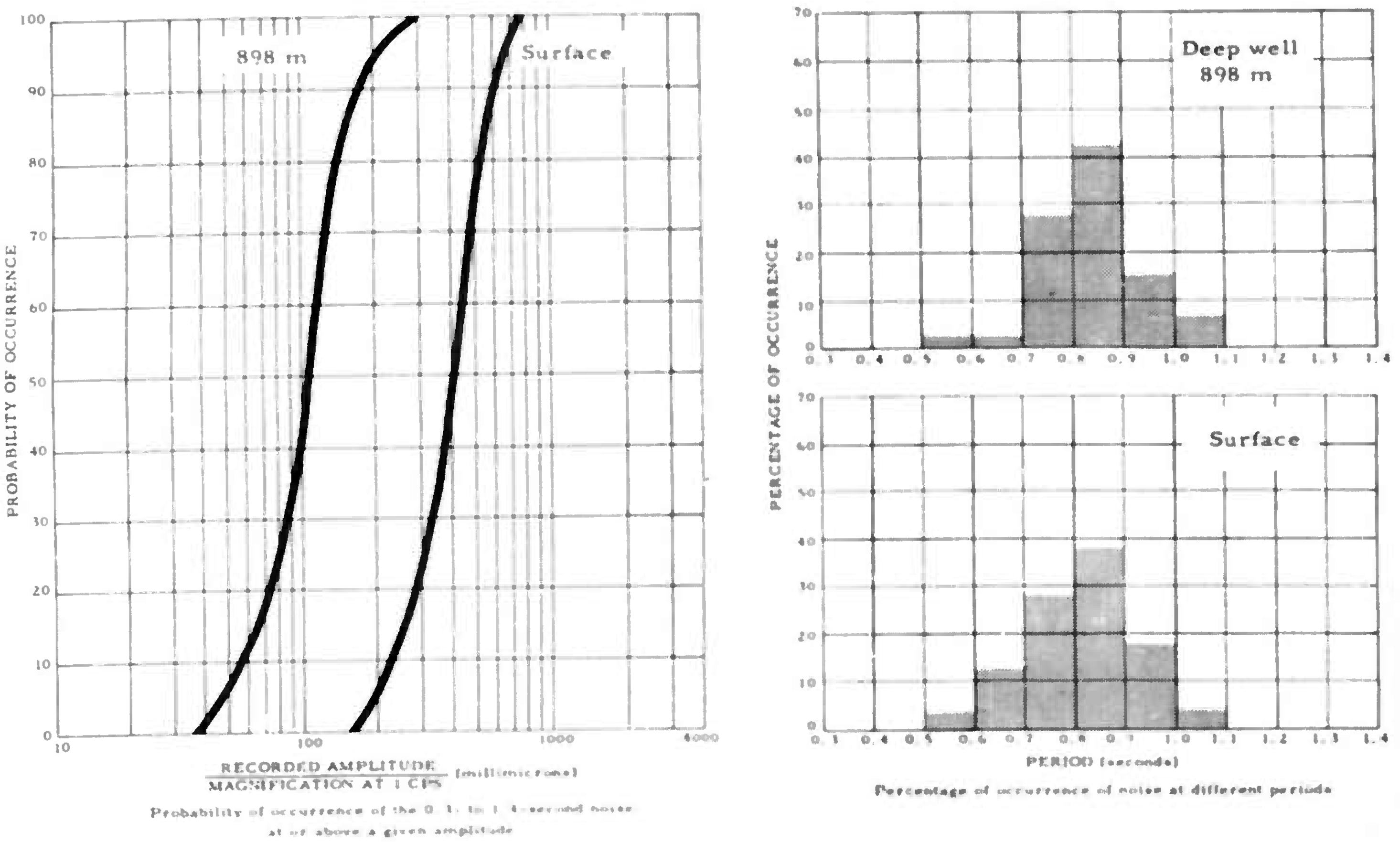


Figure 29. Probability of occurrence and percentage of occurrence of the 0.3-1.4 sec noise at the surface and in the deep well at 898 m at Eniwetok

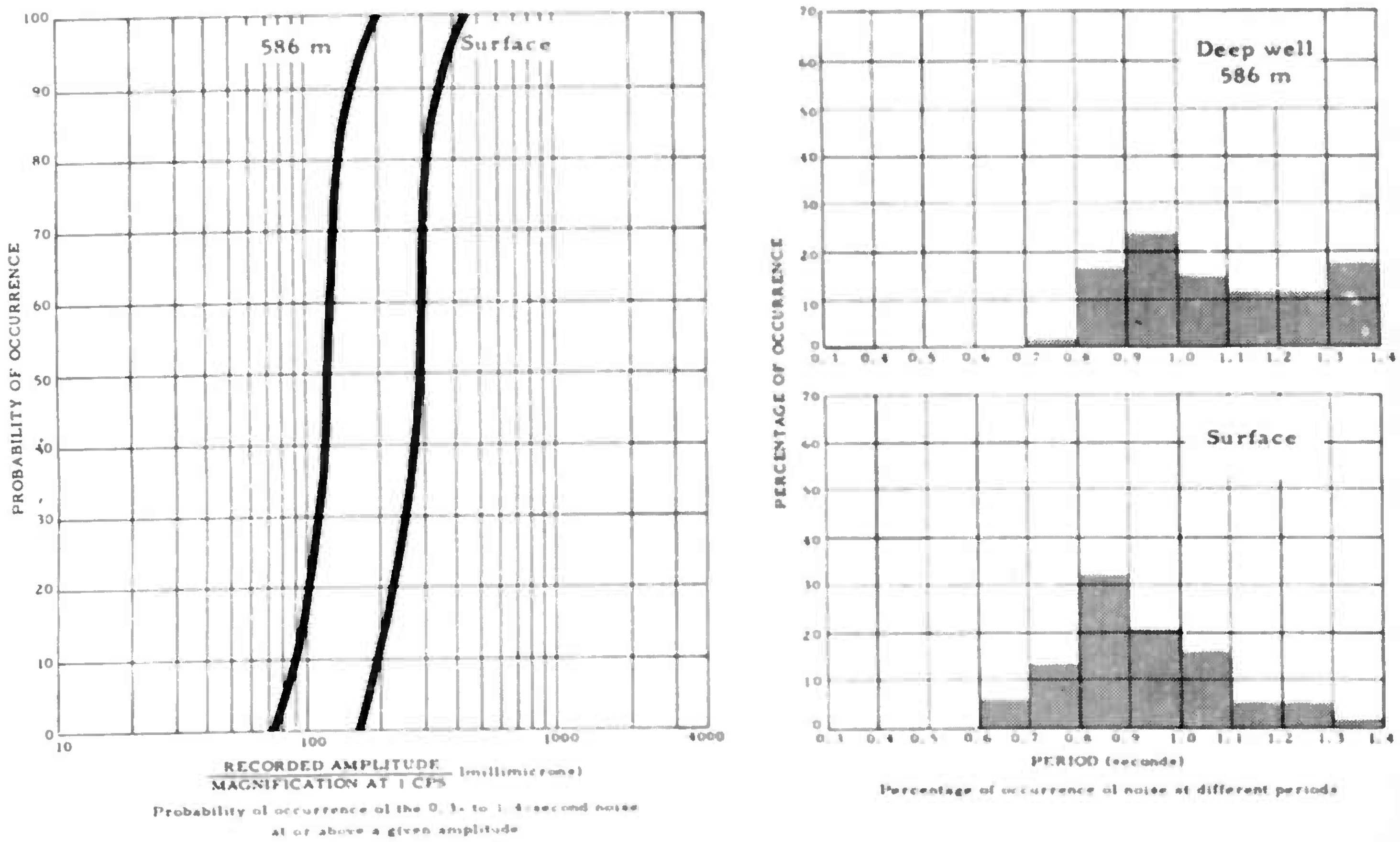
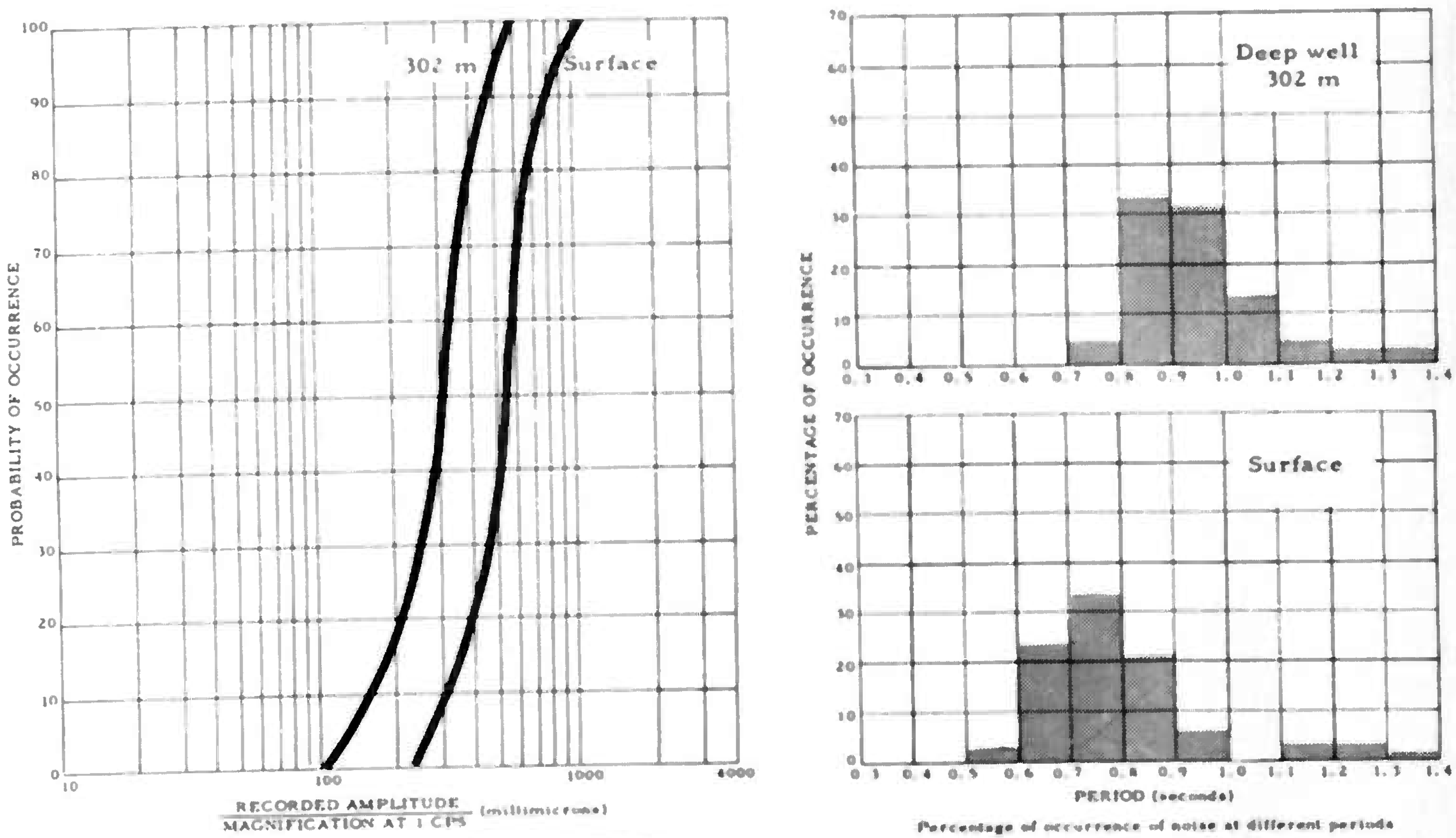


Figure 30. Probability of occurrence and percentage of occurrence of the 0.3-1.4 sec noise at the surface and in the deep well at 586 m at Eniwetok



Probability of occurrence of the 0.3- to 1.4-second noise at or above a given amplitude

Percentage of occurrence of noise at different periods

Figure 31. Probability of occurrence and percentage of occurrence of the 0.3-1.4 sec noise at the surface and in the deep well at 302 m at Eniwetok

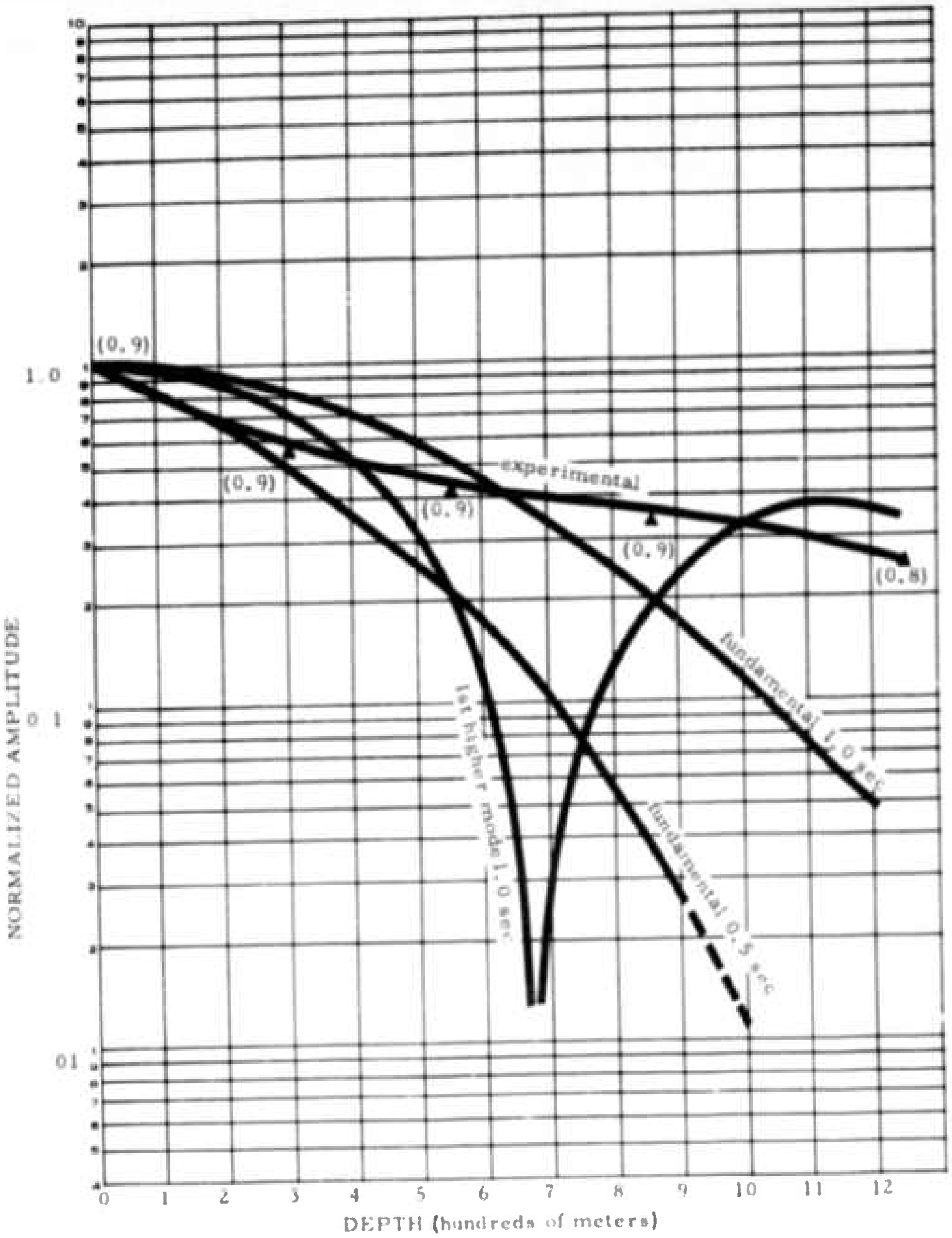


Figure 32. Plot of the theoretical Rayleigh wave amplitude decay with depth together with the experimental results obtained, Eniwetok Island. Predominant noise period in parenthesis

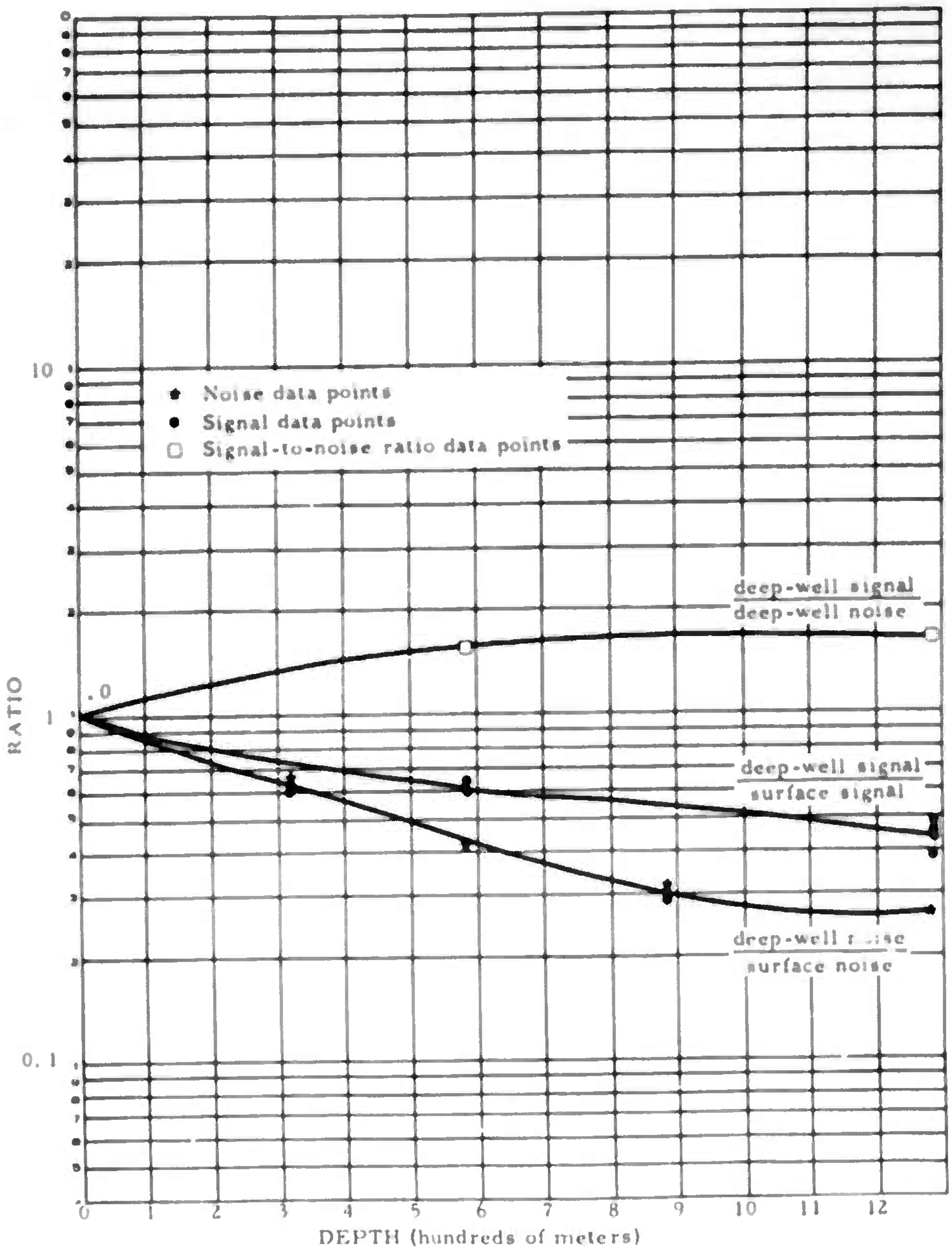


Figure 33. Plot of the decrease with depth of the signal and noise amplitudes and the increase in the signal-to-noise ratio, Eniwetok Island

The signal amplitude decreases with depth to approximately half the surface value as predicted by theory. At the surface the incident and reflected waves add to double the amplitude of the recorded P wave.

In general, only earthquakes of magnitude 5 or larger in the Pacific were detected because of the high noise background. Figures 34 and 35 show two typical signals recorded at Eniwetok.

8.3.3 Signal-to-Noise Ratios

The increase in the signal-to-noise ratio with depth shown in figure 33 was obtained by dividing (point-by-point) the signal amplitudes by the noise amplitudes given in the same figure. This technique is valid at Eniwetok because there is no change in the frequency content of the noise with depth. The following improvements in signal-to-noise ratio were obtained in the deep well:

At 586 m, the improvement is 1.4.
At 1,284 m, the improvement is 1.6.

Only a small improvement in the signal-to-noise ratio was obtained because of the shallow depth of the well and the slow decrease of the noise amplitudes.

8.4 DATA ANALYSIS, APACHE, OKLAHOMA (AP OK)

The well at Apache, Oklahoma, reaches a total depth of 2,917 m. The top half of the well consists of high-velocity limestone, and the bottom half of a complex series of volcanics of somewhat lower velocity. The lithologies and velocities are shown in figure 13.

The surface noise is low, with an average of 4.5 mμ p-p when the wind is not blowing.

Analyses of the signals and noise have not been completed, and only a few preliminary conclusions can be made at this time.

8.4.1 Noise Analysis

At Apache, the predominant 2-cps noise decreases slowly with depth. Figures 36 through 42 show the probability of occurrence and the percentage

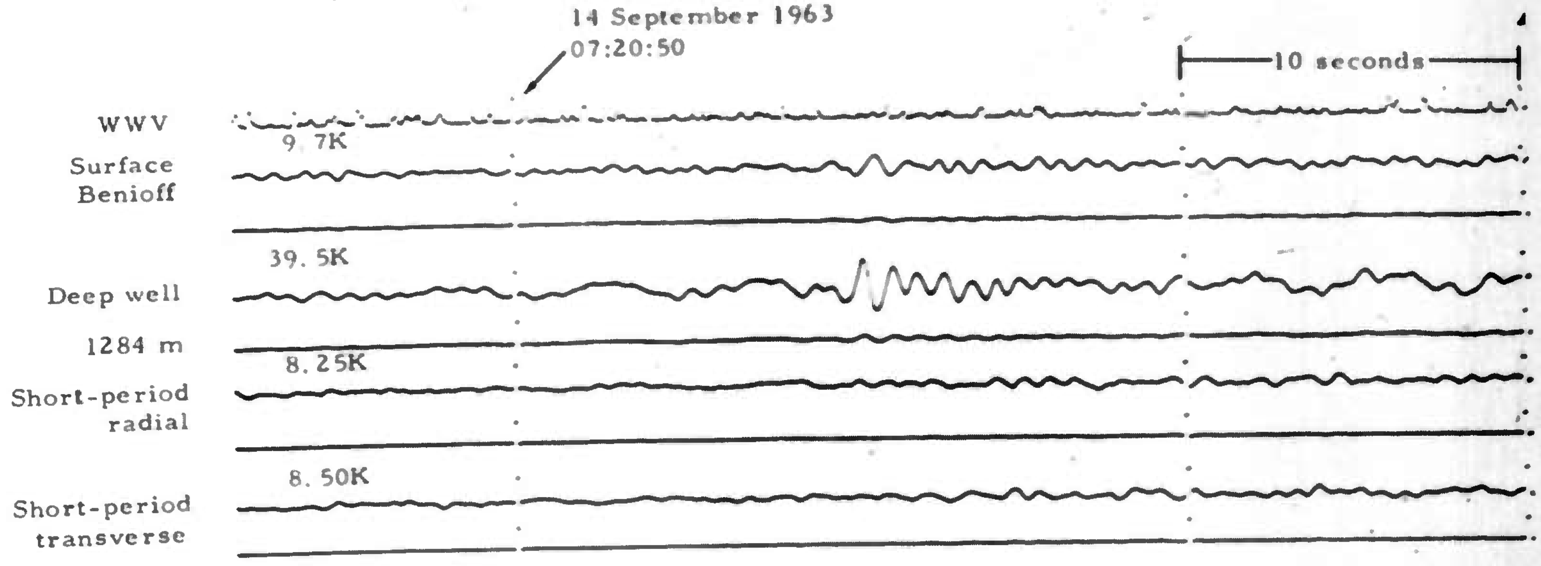


Figure 34. Recording of event by large Benioff, and deep-well seismographs at Eniwetok Island. Epicenter - Mariana Island Region. magnification at 1 cps (X10 enlargement of 16-mm film).

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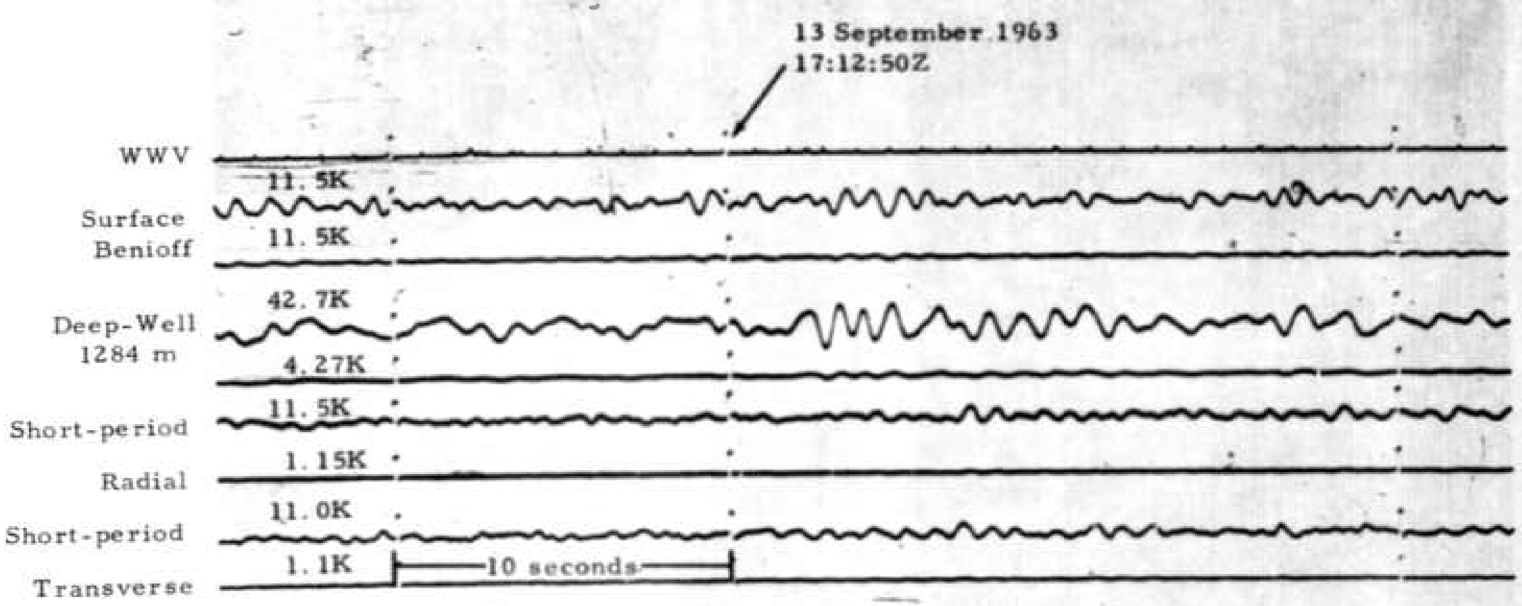

Figure 35. Recording of event by large Benioff, and deep-well seismographs at Eniwetok Island. Distance - 8494 km; time correction 0. 0, magnifications at 1 cps (X10 enlargement of 16-mm film).

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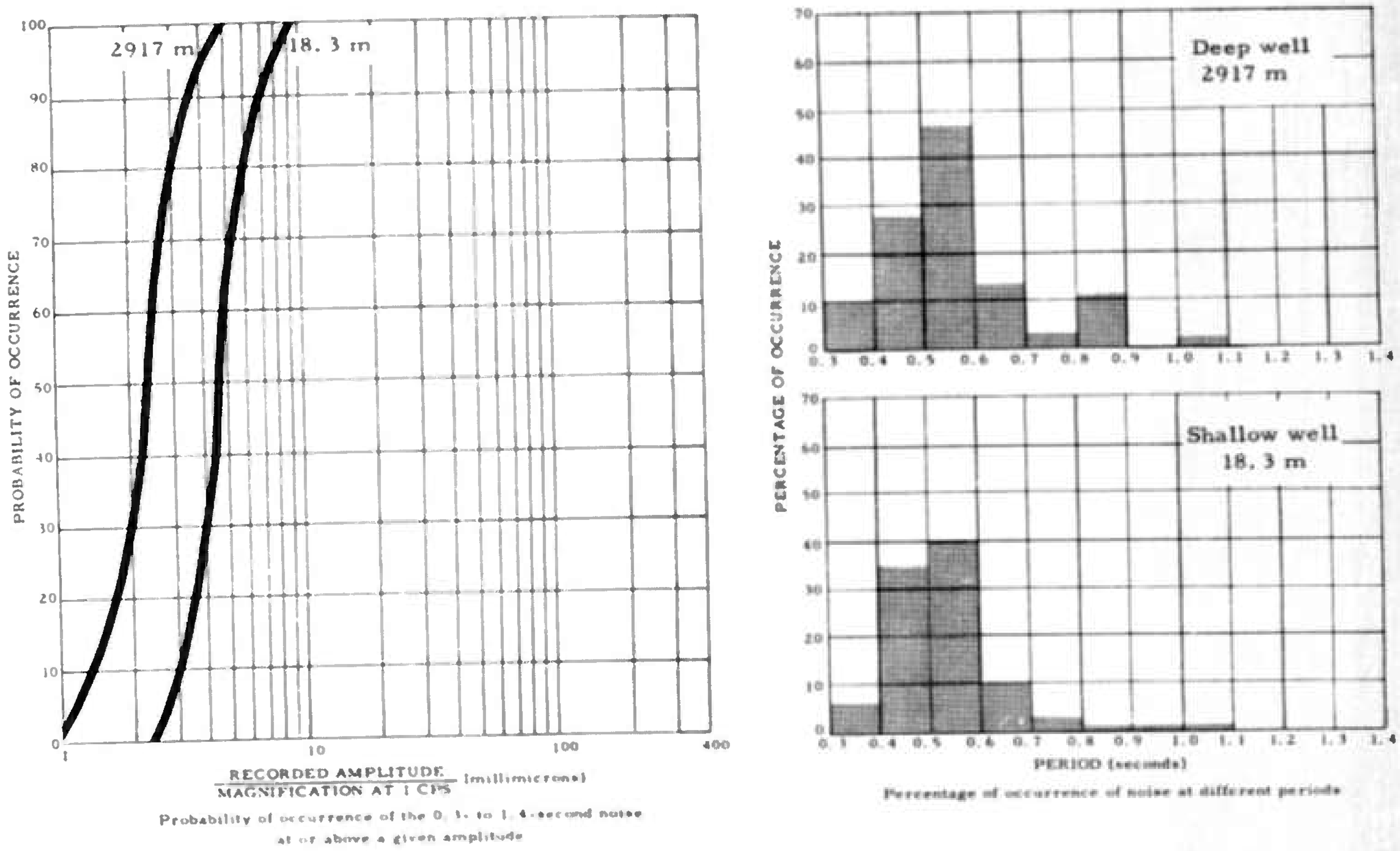


Figure 36. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 2917 m at Apache

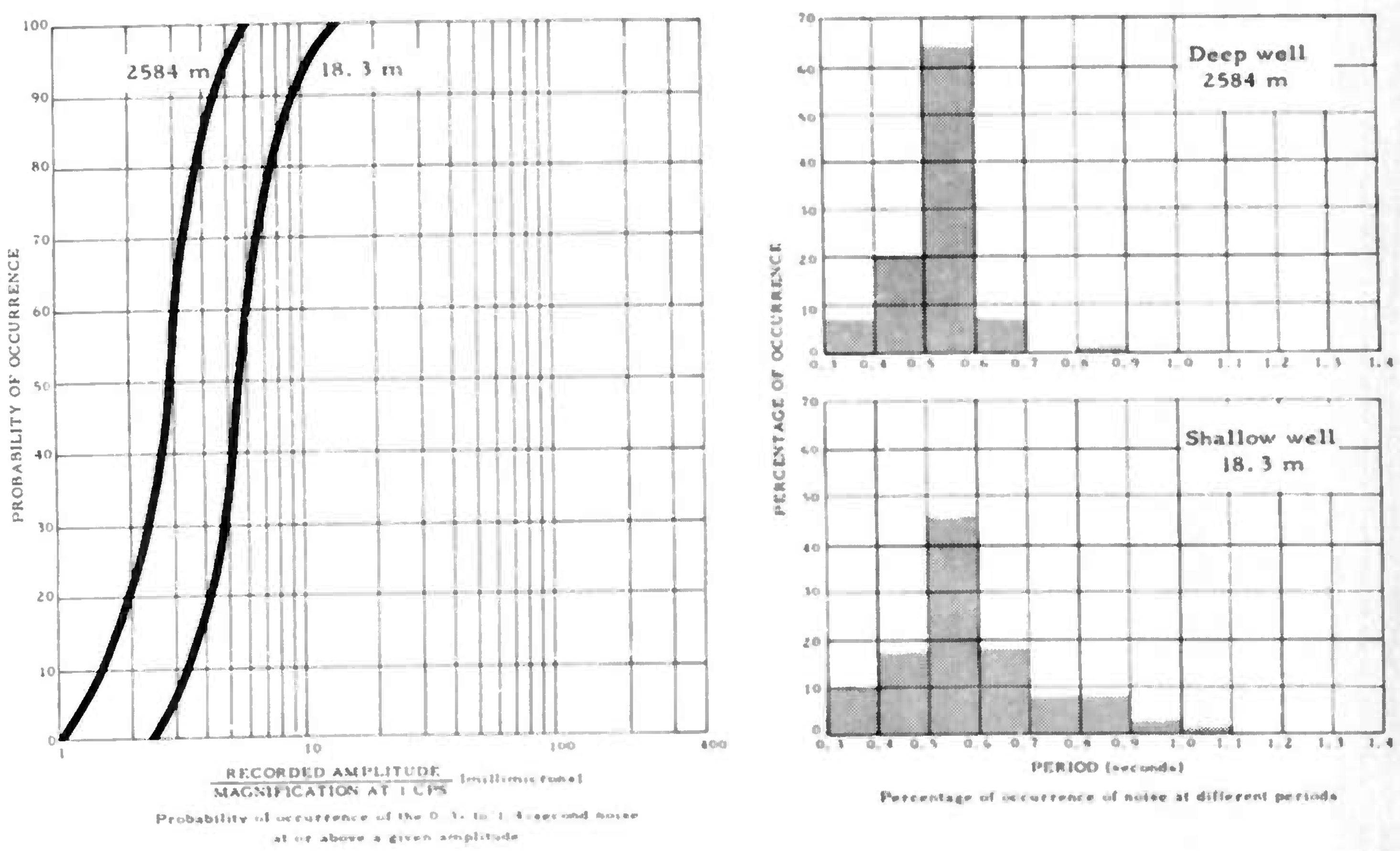
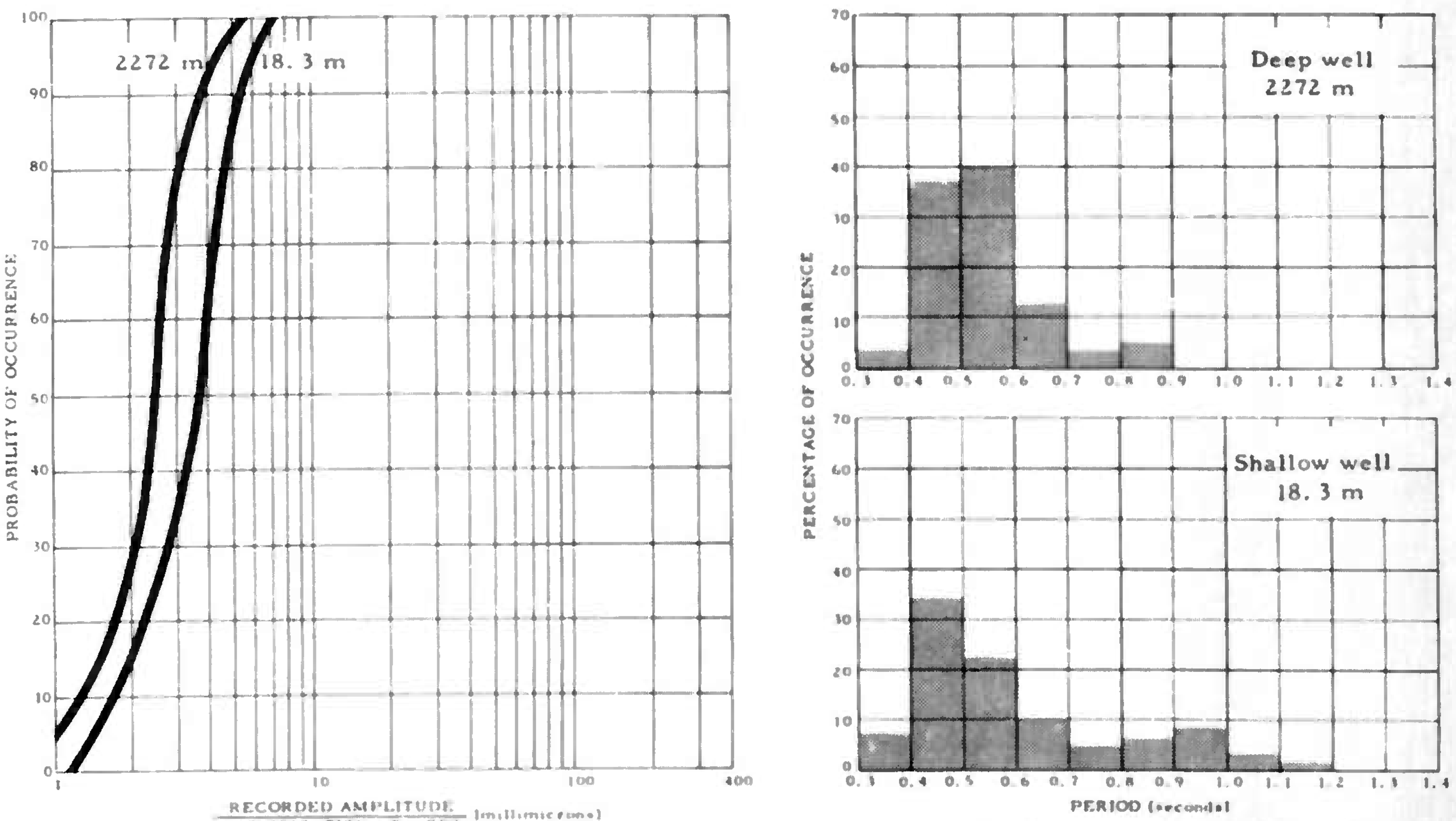


Figure 37. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 2584 m at Apache



Probability of occurrence of the 0. 3- to 1. 4-second noise at or above a given amplitude

Percentage of occurrence of noise at different periods

Figure 38. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 2272 m at Apache

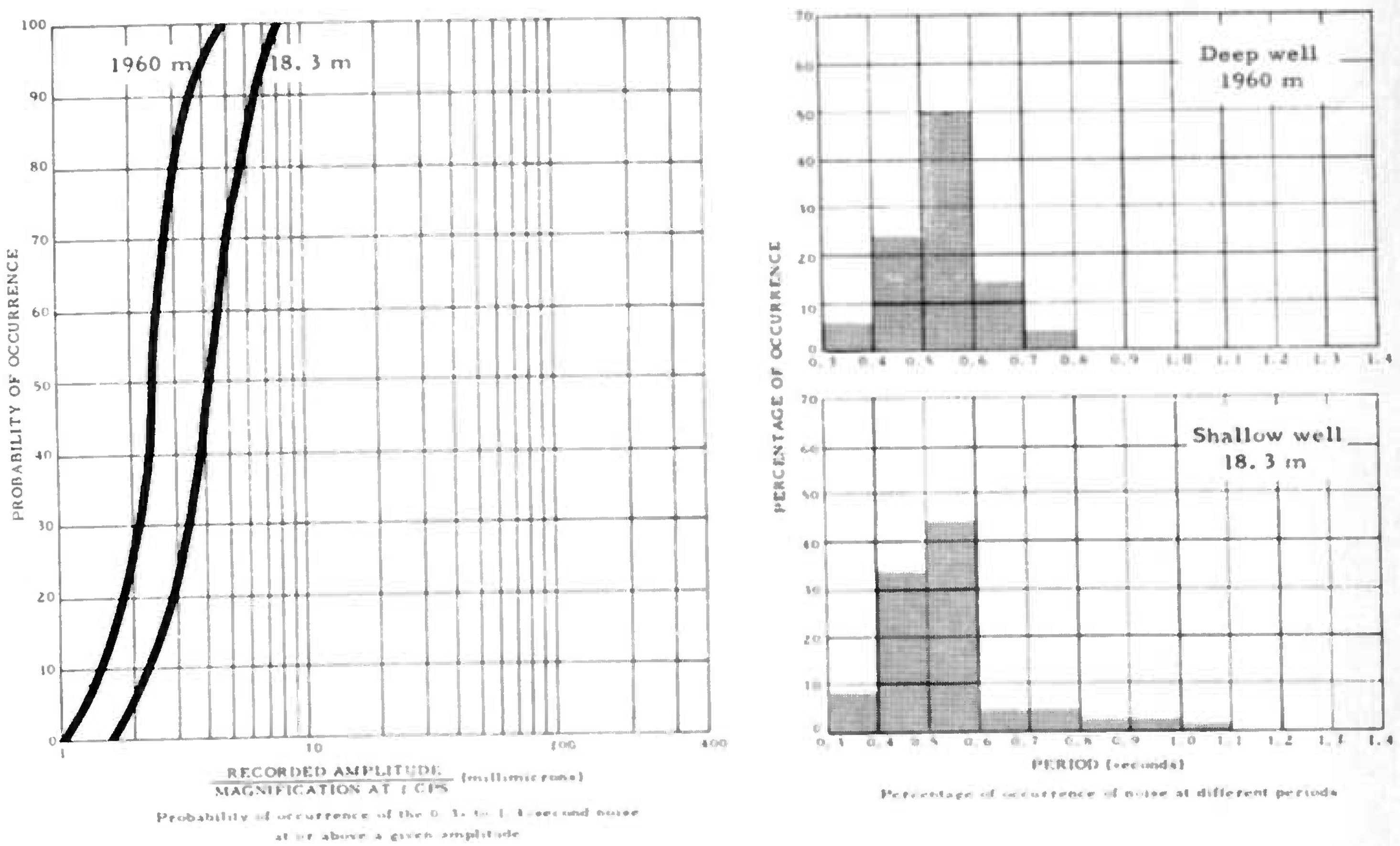


Figure 39. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 1960 m at Apache

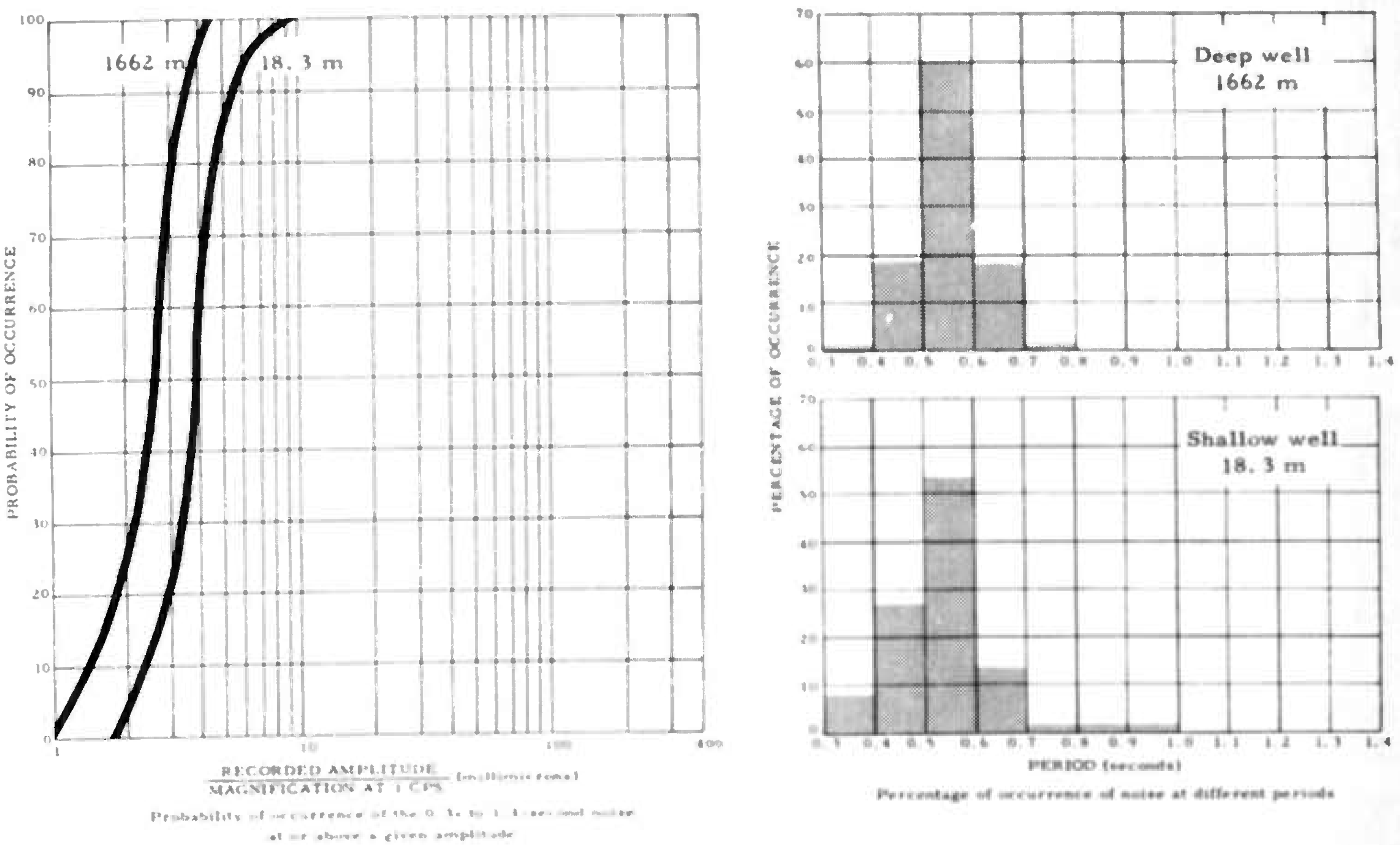


Figure 40. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 1662 m at Apache

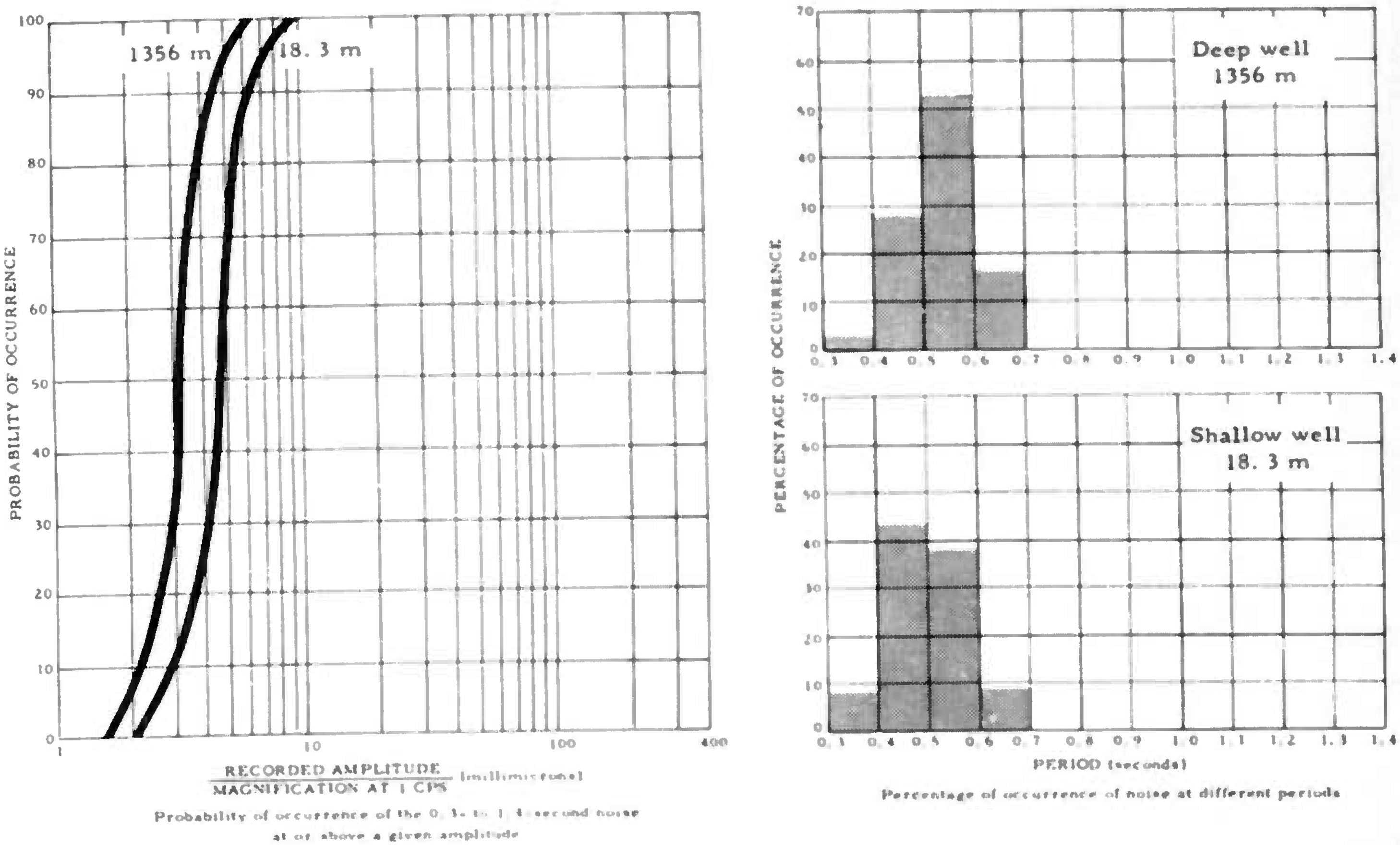


Figure 41. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 1356 m at Apache

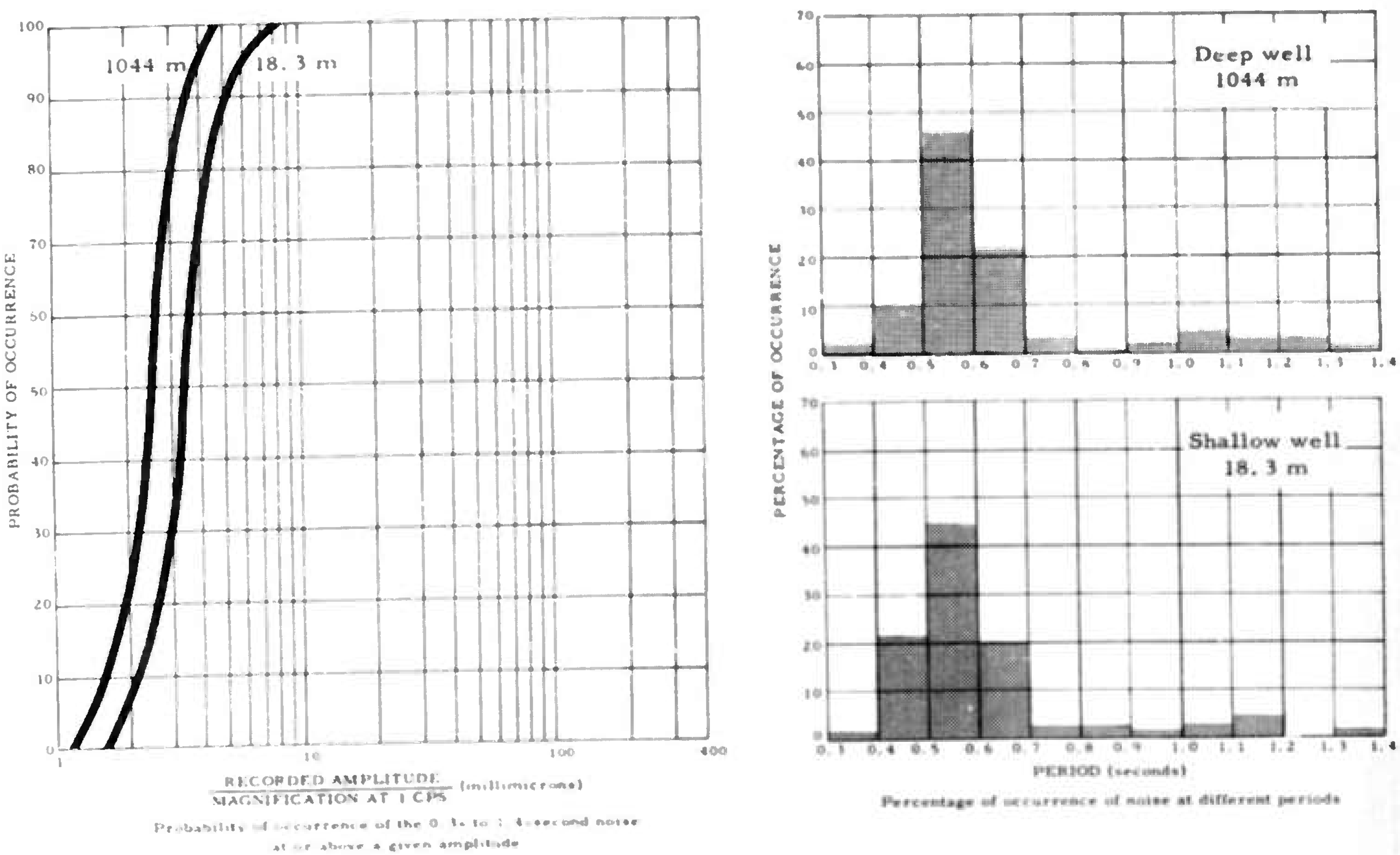


Figure 42. Probability of occurrence and percentage of occurrence of the 0. 3-1. 4 sec noise in the shallow well at 18. 3 m and the deep well at 1044 m at Apache

of occurrence curves at the depths which have been investigated to date. At the bottom of the well the average amplitude of 2-cps noise is approximately 50% of the surface value. The type of wave that is responsible for the 2-cps noise has not been identified at present.

The higher frequency (3-4 cps) cultural noise attenuates rapidly with depth and is not observed on the records from the lower half of the well.

8.4.2 Signal Analysis

Signal analysis has not been completed at Apache. Preliminary analyses indicate that the amplitude of P waves decreases at depth to approximately half the surface value, as predicted by theory.

Several simple events recorded at this site show that the small pulses received after the first arrival are also P waves. Examination of figure 43 shows that, for every pulse recorded at the surface, an incoming and a surface-reflected pulse can be found in the deep-well record. The presence of two pulses on the deep-well record indicates that the pulse is a P wave and not a surface wave generated by the first arrival.

8.5 DATA ANALYSIS, GRAPEVINE, TEXAS

The results of visual data analysis at Grapevine, Texas, are reported in detail in Semiannual Report No. 4, Project VT/1139. Data obtained since that time have not changed the conclusions reported. Results from spectral analysis at Grapevine are reported in section 8.7 of this report.

The results obtained by operating with two seismometers in the bore hole indicate the phase and amplitude coherence is good for two seismometers placed close together. Figure 44 shows an event recorded by seismometers at 2,715 m and 2,783 m.

Results obtained with seismometers at 1,214 m and 1,829 m indicate there is no visually detectable coherence in the high-frequency (2-3 cps) noise. At these depths there is no cement behind the casing and some of the lack of coherence may be due to poor coupling. Figure 45 shows an event received with a separation of 615 m. Addition and subtraction of two seismograph traces at Grapevine, Texas, is discussed further in section 8.6.

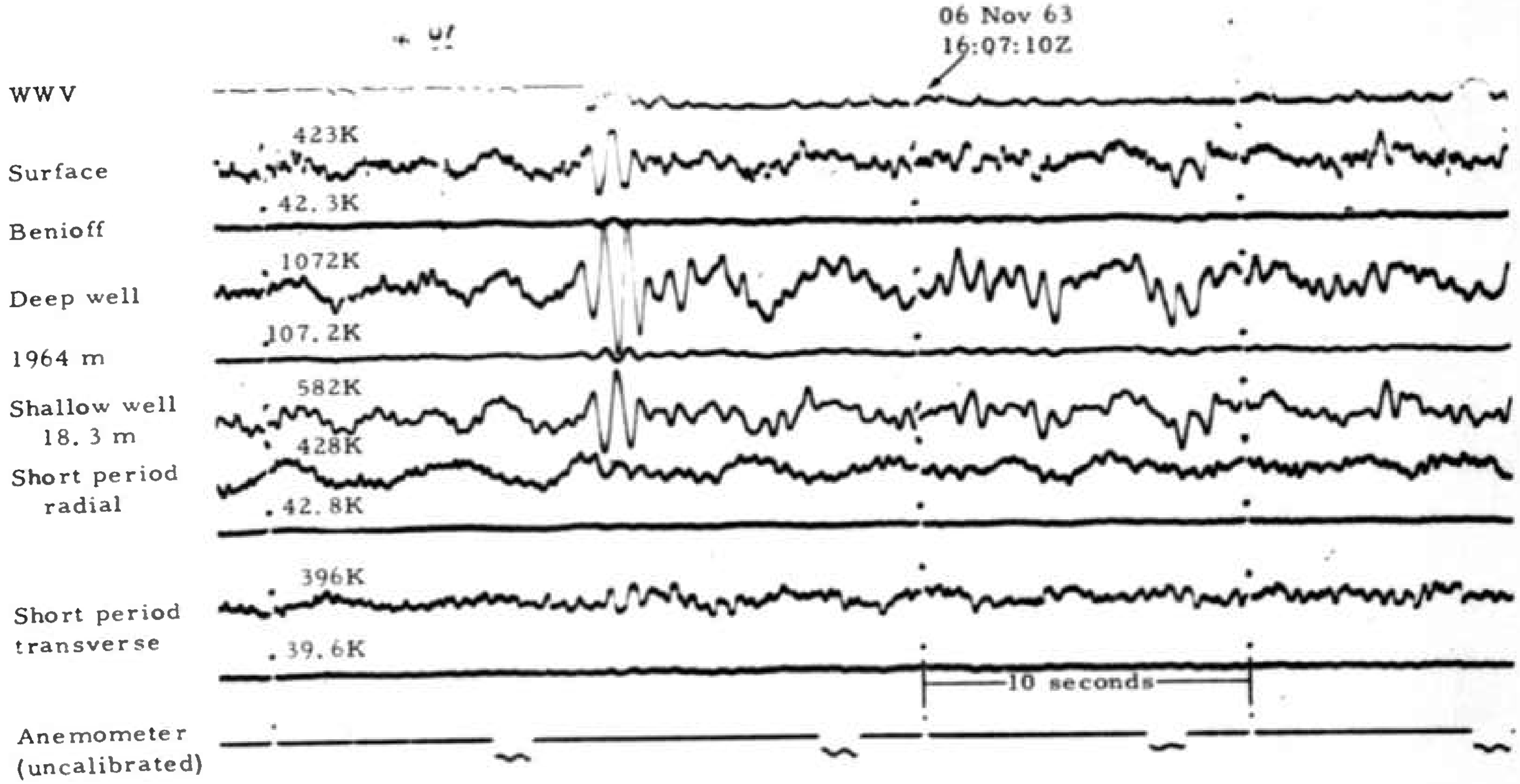


Figure 43. Recording of event by small Benioff, deep-well, and shallow-well seismographs at Apache, Oklahoma. Epicenter unknown, magnification at 1 cps (X10 enlargement of 16-mm film).

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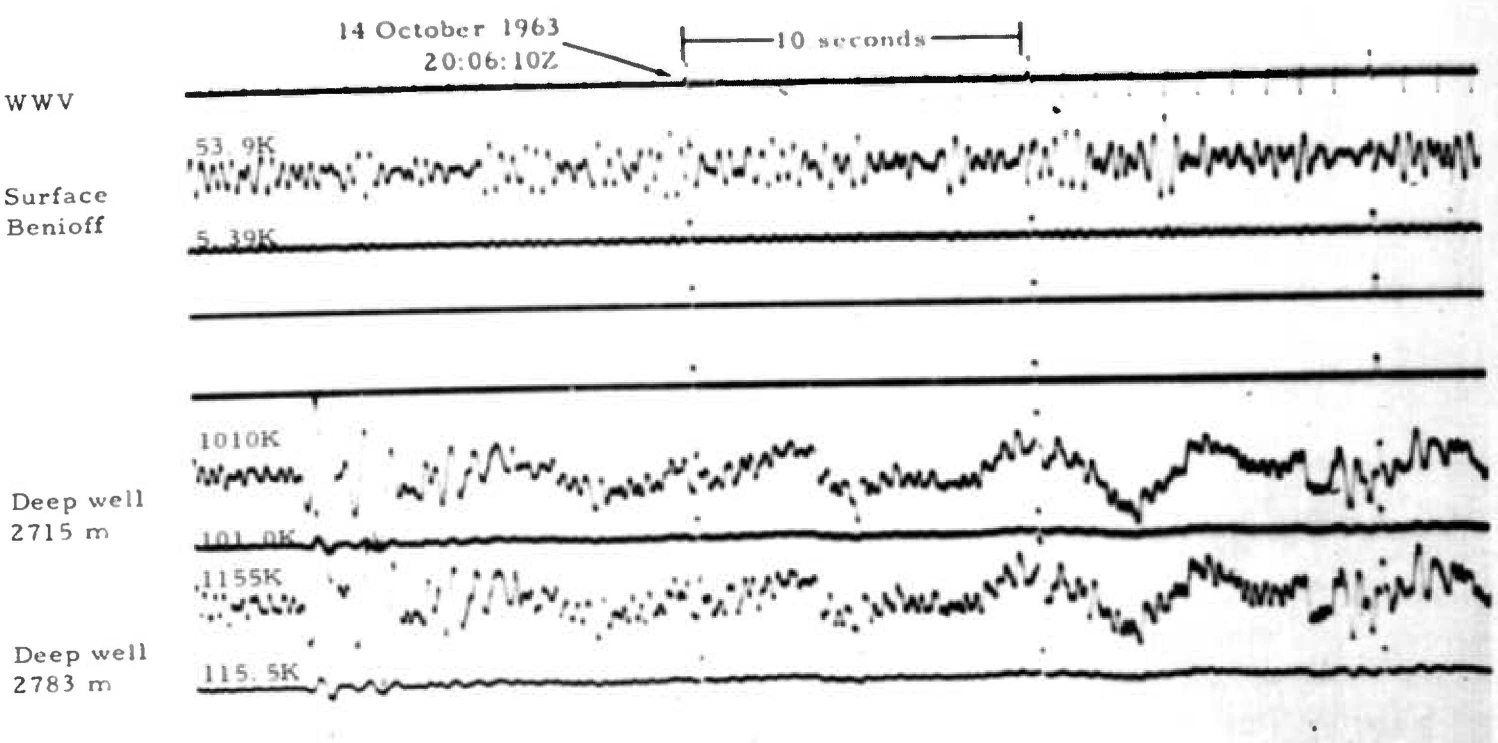

Figure 44. Recording of event by a large Benioff and two deep-well seismographs at Grapevine, Texas. Epicenter unknown. Magnifications at 1 cps (X10 enlargement of 16-mm film).

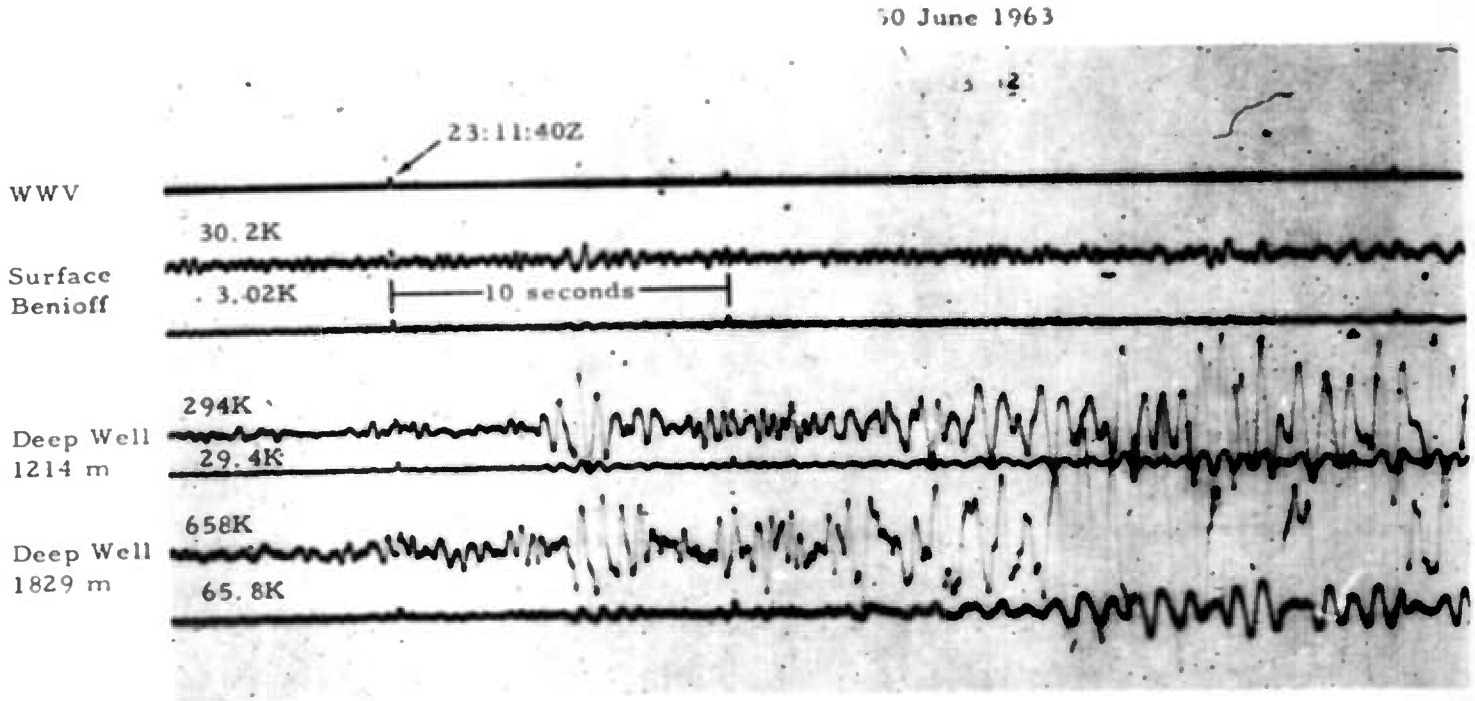

Figure 45. Recording of event by large Benioff and two deep-well seismographs at Grapevine, Texas. Epicenter unknown, magnification at 1 cps (X10 enlargement of 16-mm film).

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8.6 INSTRUMENTATION, MULTIPLE SIGNAL PROCESSING

8.6.1 Description

When recordings are made simultaneously from more than one deep-well seismometer, summation or subtraction of the signals may improve signal-to-noise ratio or enhance detection capability. It is desirable to be able to time delay the signal from one seismometer and to filter the signals as desired. Equipment has been assembled to permit these functions to be performed.

Magnetic-tape records from the field, recorded at 0.3 inch per second (ips) are re-recorded at 0.6 ips. The magnetic tape is then scanned at 666-2/3 ips with the experimental Analysis Automation Scanning Drum. The frequency of the original tape signal is thus multiplied by 1111.1 (666-2/3 ÷ 0.6). The resultant higher frequency of the output permits compact, simple filters and time-delay devices to be used.

The system that has been assembled is shown in block diagram form in figure 46. Except for the time-delay device in one channel, the two channels are as similar as possible so they may have similar transfer functions in the frequency range of interest.

The delay unit used is the Ad-Yu Electronics Lab, Inc. Model 802e. This model has four step-variable delay lines, each consisting of a set of m-derived networks. The maximum delay obtainable is 2 milliseconds, which is equivalent to 2.22 sec in real time.

The attenuation in the delay line is 6 db with no delay applied. For frequencies less than 2 kc, the total attenuation increases with delay up to a maximum of 7.5 db. Above 2 kc, the amplitude becomes frequency dependent and is down an additional 3 db at 5 kc.

Each filter consists of a low-pass section and a high-pass section connected in series. A section consists of four passive cascaded filters coupled by emitter followers. The filters have unity gain.

The real-time frequency range is 0.66-10 cps in the low-pass section and 0.2-3.0 cps in the high-pass section. At any particular frequency the rejection rate may be selected in 6-db steps from 6 db/octave to 24 db/octave.

The output signals from the filters are isolated by resistors before they are added or subtracted. The output is viewed on an oscilloscope and a Polaroid camera is used to make permanent records.

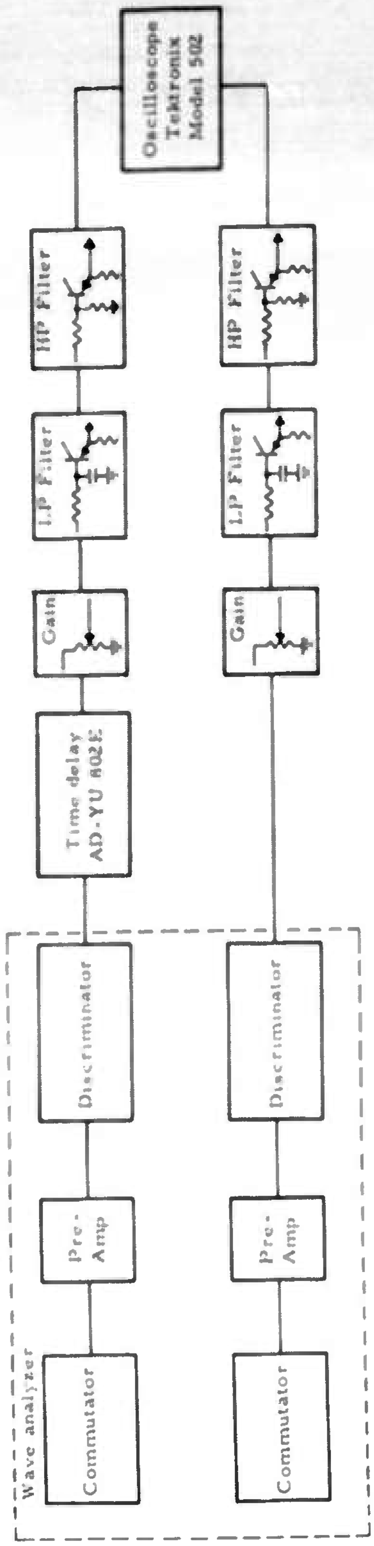


Figure 46. Block diagram of the deep-well playback unit

8.6.2 Results

The apparatus was built in order to employ signal addition and subtraction as a method of increasing the signal-to-noise ratio and detecting first motion. It has also proved useful in direct visual comparison of signals.

8.6.2.1 Summation

Figure 47 shows an event which was recorded at depths of 1,214 m and 1,829 m at Grapevine, Texas. The addition of the signals, with an appropriate time delay applied, improves the signal-to-noise ratio slightly. The reflection from the earth's surface, which appears on both records, is attenuated when the signals are delayed and added.

8.6.2.2 Subtraction

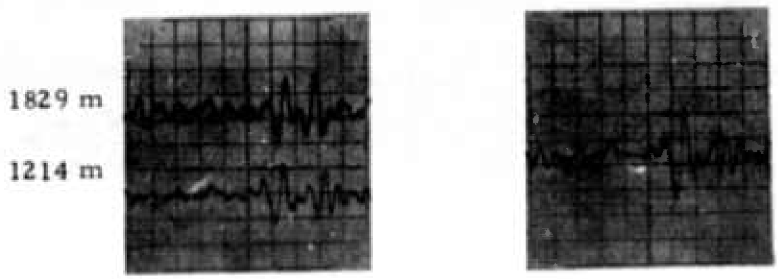
Figure 48 shows a signal recorded at Grapevine at depths of 2,710 m and 2,770 m. At 2,730 m there is a velocity transition from approximately 4,270 m/sec to 5,500 m/sec, thus there should be a difference in signal amplitudes, but the noise background should be virtually identical. Figure 48 also shows the subtraction of one signal from the other. With the separation used between instruments in this experiment, the signal amplitude difference was not sufficient to enhance the signal-to-noise ratio by subtracting signals to minimize the noise. With a greater velocity discontinuity, producing a larger change in P-wave amplitude, the same degree of cancellation of the noise would possibly produce an improvement in signal-to-noise ratio.

8.7 RAYLEIGH WAVES IN THE NOISE

8.7.1 Introduction

Spectral analysis of the noise at Grapevine and visual analysis of the data at other sites indicate that the vertical component of the noise is composed mainly of fundamental and higher mode Rayleigh waves.

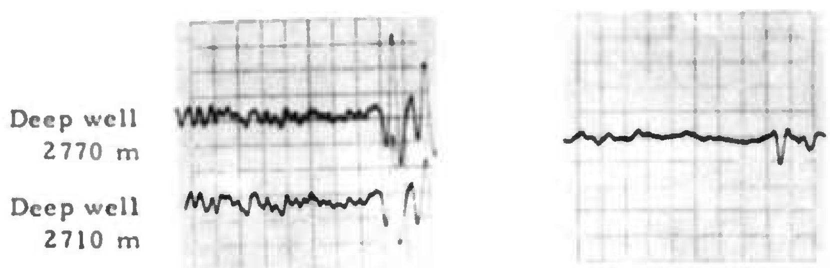
Waves of other types may also be present in special cases, e.g., the wave-guided noise encountered at Hobart, Oklahoma (Semiannual Report No. 4, Project VT/1139). Body waves may be present at depths where Rayleigh waves have been greatly attenuated. For example, the 2-3 cps noise at 3,000 m at Grapevine must be composed of either body waves or a mixture of higher mode Rayleigh waves.



Individual signals, time delayed

Time delayed and summed

Figure 47. Reproduction of small P wave recorded on deep-well seismometers at depths of 1214 m and 1829 m, showing time-shifted summation, Grapevine, Texas



Individual signals

Subtraction (signal at 2770 m - signal at 2710 m)

Figure 48. Signals recorded at Grapevine, Texas, at depths of 2710 m (8910 ft) and 2770 m (9103 ft). Filter bandpass 0.66-30 cps

By the use of two or more seismometers in the deep well, the energy present in each type of wave can be determined; however, the theory for the decrease of Rayleigh waves with depth must be correct for the approach to be successful. As shown in section 8.7.2 of this report, the assumptions made in calculating the decrease of Rayleigh wave amplitude with depth need to be changed.

8.7.2 Higher Mode Rayleigh Waves

Spectral analyses were performed of 200- and 300-sec digitized samples of noise recorded on the surface and in the deep well at 3,000 m at Grapevine, Texas.

Figures 49 and 50 show the spectrograms of, and the phase relationships between, the noise at the surface and in the deep well.

Periods longer than 2.2 sec behave as fundamental mode Rayleigh waves. The waves are in phase between the surface and 3,000 m, and the amplitude decreases faster for the shorter periods, as expected.

Between the periods of 1.0 and 2.2 sec, the noise is approximately 180 deg out of phase between the surface and 3,000 m (figure 50). Furthermore, the ratio of surface to deep-well noise shown in figure 49 indicates that the amplitude ratio no longer decreases with decreasing period, but rises to a peak at 1.5 sec. The behavior of the noise in this period range indicates that the noise is composed almost exclusively of first higher mode Rayleigh waves, which are known to be 180 deg out of phase at depth and which do not decrease exponentially in amplitude as does the fundamental mode.

For periods shorter than 1 sec, the noise is greatly attenuated with depth; however, neither the decrease with depth nor the phase relationships indicate clearly which types of waves are present in the noise. The rapid attenuation does indicate a predominance of fundamental mode, which is the only Rayleigh mode that attenuates rapidly enough to explain the experimental results. In this period range there is considerable amplitude difference be between spectrograms taken at different times.

Spectral analyses were also run for several depths in the well at Grapevine, Texas. Because of the possible reduced coupling of the seismometer to the earth, the spectra may not be accurate; however, the phase relationships contribute some important information toward a better understanding of the noise.

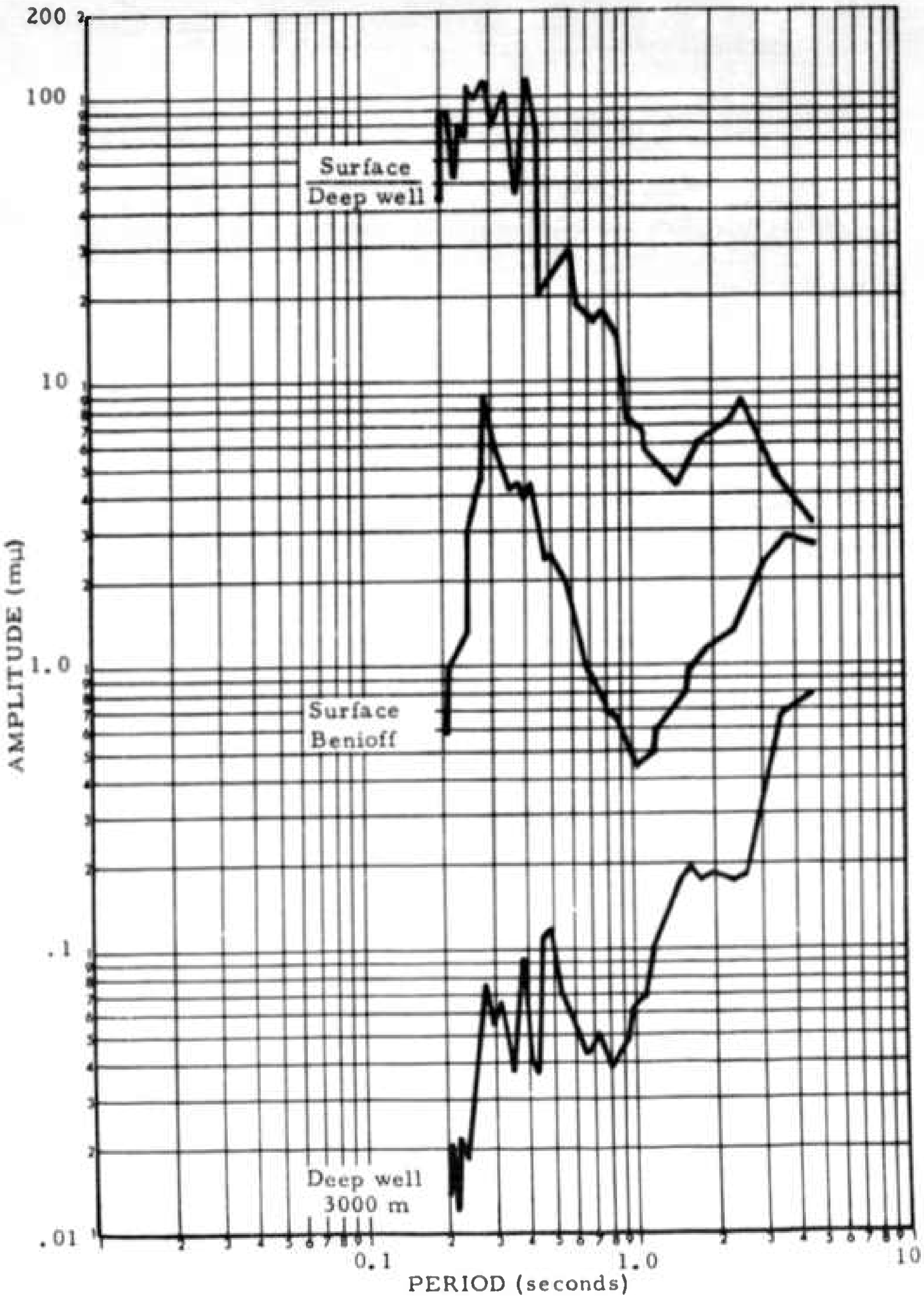


Figure 49. Spectral analyses of 300-sec noise samples at the surface and at 3000 m, Grapevine, Texas

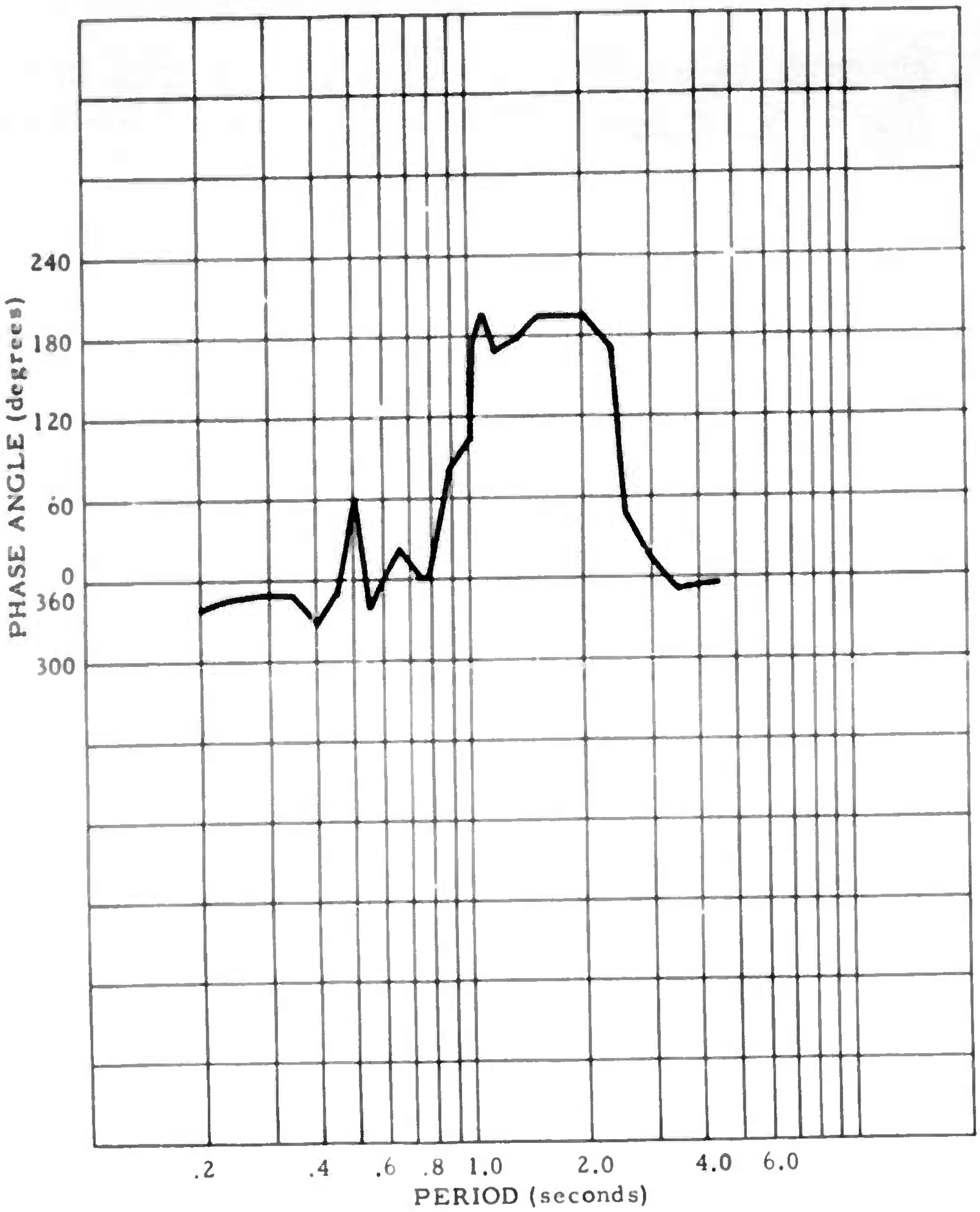


Figure 50. Graph showing the phase relationship between the surface and 3000 m level noise at Grapevine, Texas

Figure 51 shows the phase relationships between noise samples recorded at the surface and at various depths. The longer period microseisms are always in phase. At depths of 2,430 m and 2,700 m, the noise is 180 deg out of phase between periods of 2.1 and 0.9 sec. At depths less than about 900 m, this 180-deg phase change is not observed. At depths between 2,430 m and 900 m, the phase change occurs at periods between 2.1 and 0.9 sec.

Figure 52 shows the period at each depth where the phase curves departed from the in-phase relationship. Somewhat arbitrarily, the 90-deg point was plotted, as shown on figure 51.

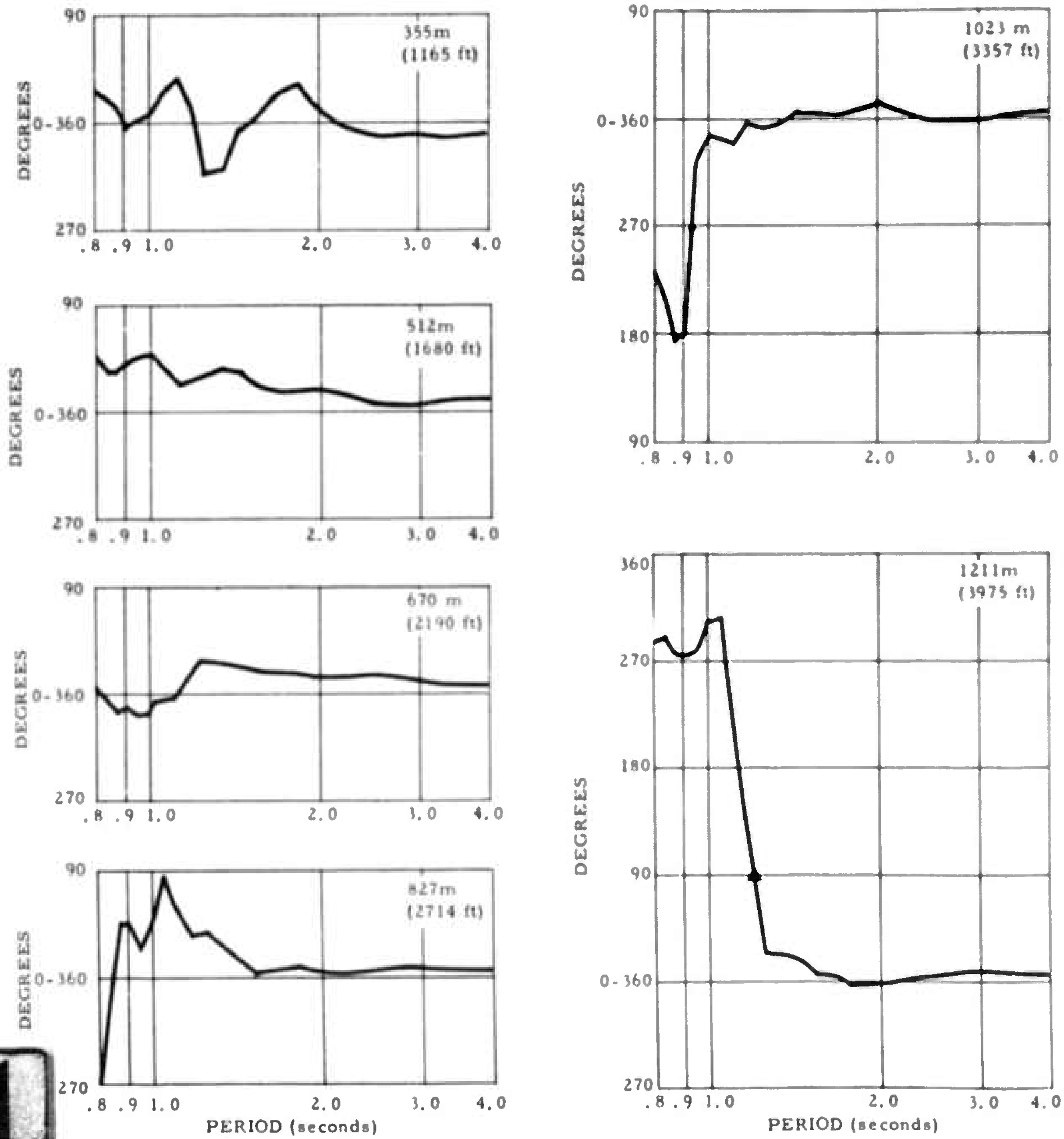
Under the assumption that the first higher mode Rayleigh wave is always present at periods between 0.9 and 2.1 sec, the experimental curve shows the location of the nodal points of first higher mode Rayleigh waves. The first higher mode is in phase with the surface above the nodal point, and the 180-deg phase change will not be found.

The theoretical nodal points are also plotted on figure 52. The discrepancy between the theoretical and experimental points increases with increasing period. The theoretical model appears to be in error, because higher velocities deeper in the crust were not considered.

9. ADMINISTRATION

The personnel listed below prepared this report and supervised the work.

Richard M. Shappee	Program Manager
T. G. Brown	Group Leader, Well Preparation
E. J. Douze	Group Leader, Data Analysis
R. F. Knight	Group Leader, Systems Engineering


355m
(1165 ft)
512m
(1680 ft)
670 m
(2190 ft)
827m
(2714 ft)
1023 m
(3357 ft)
1211m
(3975 ft)
DEGREES
90
0-360
270
180
.8 .9 1.0 2.0 3.0 4.0
PERIOD (seconds)

1

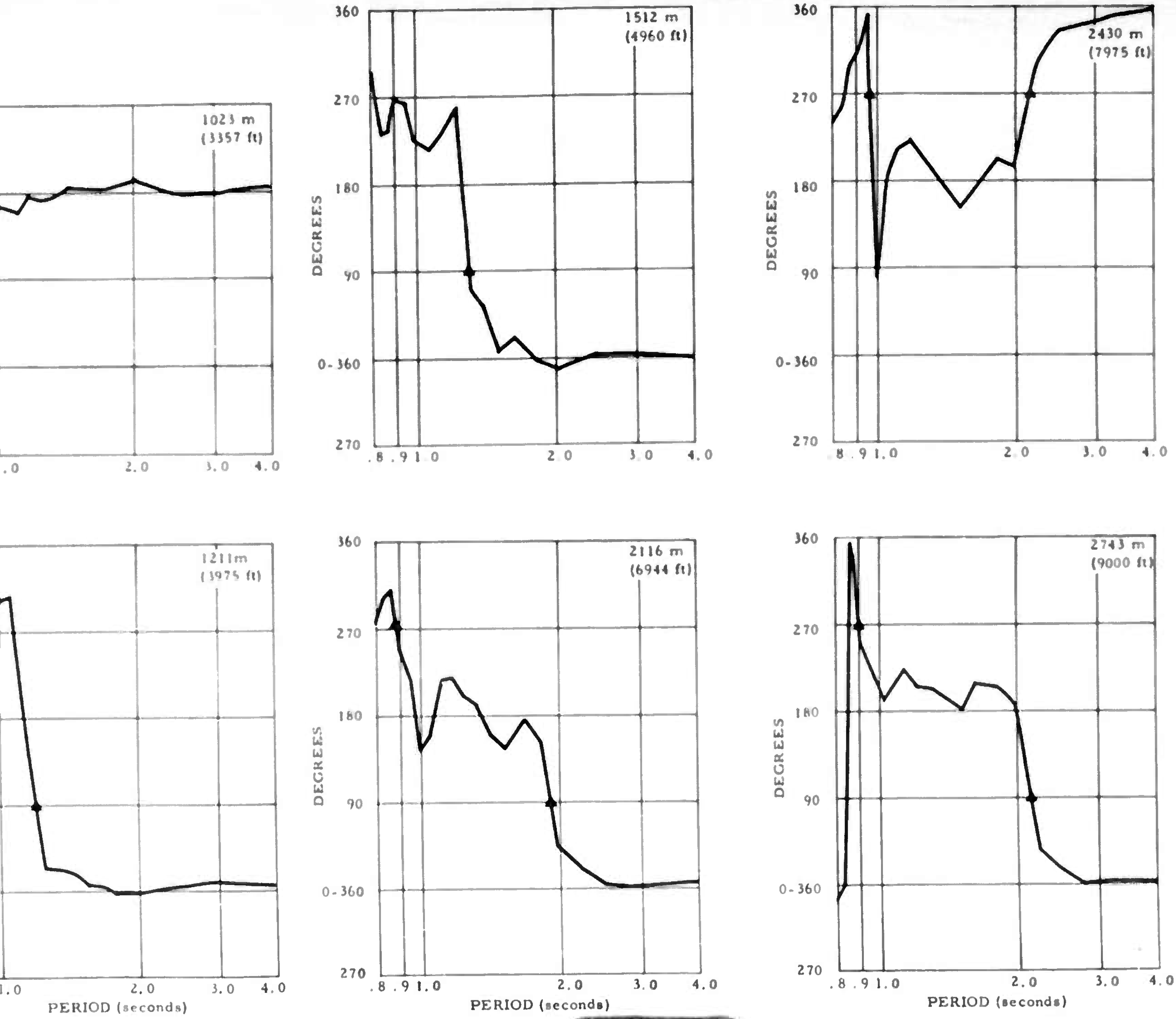


Figure 51. Plot of the phase relationship between the surface and various depths versus period. Grapevine, Texas

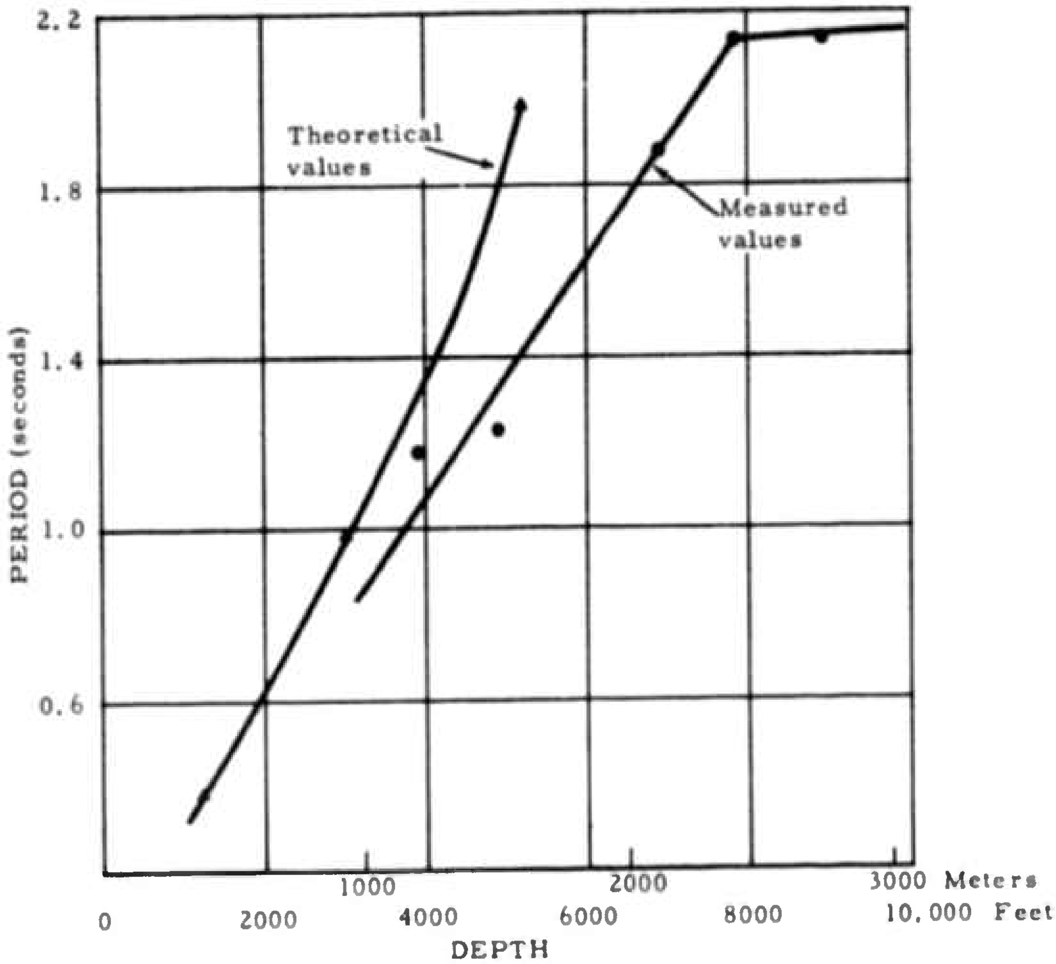


Figure 52. Period versus the depth at which the first higher mode Rayleigh wave nodal points were found experimentally at Grapevine, Texas

APPENDIX 1 to TECHNICAL REPORT NO. 63-99

AMENDMENT TO STATEMENT OF WORK TO BE DONE
PROJECT AUTHORIZATION NO. VT/1139

APPENDIX 1 to TECHNICAL REPORT No. 63-99

AMENDMENT TO STATEMENT OF WORK TO BE DONE PROJECT AUTHORIZATION NO. VT/1139

1. **Tasks**. Paragraph 1, Tasks, of the basic Statement of Work to be Done is amended by the addition of the following tasks:

"h. Using the deep well variable reluctance seismometer developed and tested under the provisions of tasks a through f, conduct a field measurement program to investigate geological and other factors which influence the signal-to-noise improvement obtained by operating seismometers in deep wells. In the course of this work, accomplish the following subtasks:

"(1) Investigate and catalog existing deep boreholes which may be suitable for conducting seismic measurements at depths as great as 10,000 feet. This work is to be accomplished in close coordination with the AFTAC Project Officer, who will assist in obtaining information on deep wells from other VELA sources. Recommend to the Government sites which appear to be suitable for conducting studies of noise and signals as a function of depth, geological structure, and other environmental conditions. Support such recommendations by reports covering technical and cost factors.

"(2) Upon obtaining approval by the Government, conduct such additional surveys as are needed, make all necessary legal and support arrangements at the sites chosen, and prepare and occupy these sites for the field program.

"(3) Make field measurements of noise and signal amplitudes at various depths within these holes. Simultaneous measurements are required at two depths, which may be separated from several feet to several thousand feet. For planning purposes, it may be assumed that approximately eight sites will be occupied for a period of approximately 90 days each. It is expected that two mobile field crews will be required for this subtask. Two mobile seismic stations with operating personnel will be made available from Project VT/074.

"i. Using the deep well variable reluctance seismometer developed and tested under the provisions of tasks a through f, measure and study the physical characteristics of deep wells and determine methods of emplacing seismometers to optimize the detection of small signals in the presence of noise. In the course of these studies, perform the following subtasks:

"(1) Operate and improve the deep well and facilities at the test site previously established near Grapevine, Texas. Set up additional prefabricated shelters as necessary, drill additional shallow and medium depth wells as needed, and install appropriate recording and reference instrumentation.

"(2) Operate deep well instrumentation and perform experiments to investigate the effect of changes to the size and type of well casings, changes of well fluids, methods of cementing casings, and other factors. Continuous seismograph operation in this cubtask is not required, although operations should continue for sufficient periods to investigate the operational life of the instruments. It is to be expected that one field crew will be required for this subtask, in addition to the two field crews mentioned under paragraph h (3) above. A mobile seismic station with operating personnel from Project VT/074 will provide support for this task.

"(3) Through systems engineering investigations, improve the seismograph design by adapting the instrumentation to borehole characteristics as determined by experience. Monitor instrument performance under Task h, above, and conduct engineering design and development work needed to improve operational performance.

"j. Prepare, equip and install appropriate deep well instrumentation in a borehole near a permanent seismic station in at least one location designated by AFTAC. Site preparation will follow specifications developed under Paragraph i, above. The signals from this deep well instrumentation will be transmitted to the permanent seismic station for comparison with surface array signals and to determine performance and long term operational reliability.

"k. Under AFTAC technical guidance, process the raw data obtained from field measurements and perform detailed seismic analysis and evaluation, making comparison between observations and theoretical studies on the

investigation of signal vs noise as a function of depth, geology and environment. Develop quality control procedures as necessary to properly direct the field measurement effort. The analytical program will be supplemented by computational and analytical work accomplished at other facilities under AFTAC control. It is intended that programming and other computational services will be accomplished by the contractor. However, services of a high-speed computer of the CDC 1604 class will not be arranged for under this project without AFTAC concurrence."

2. Reports, Paragraph 2, Reports, of the basic Statement of Work to be Done is amended to read:

"a. Monthly letter type progress report in 15 copies, summarizing . . .

"d. A semi-annual technical summary report in 40 copies, covering work . . .

"e. A technical report, in 50 copies, covering all work through task 1g will be submitted within 60 days following completion of this body of work. A final technical report, in 50 copies, covering the extended work, tasks 1h, et seq., will be submitted within 60 days following completion of this later work. The headings of these reports will contain the information indicated in paragraph 2a, above, and each report will include all of the pertinent information of the related semi-annual reports."

3. Technical Documents. Paragraph 3a, Technical Documents, of the basic Statement of Work to be Done, is amended to read:

"a. Technical manuals on the installation, calibration and operation of all technical equipment recommended for routine operation of a deep hole seismographic system."

A new paragraph c, is added to read:

"c. Seismograms and field operational logs as requested by the AFTAC Project Officer."

4. Time Schedule. Paragraph 5, Time Schedule, of the basic Statement of Work to be Done is amended as follows:

"5. Time Schedule. Work should be completed in accordance with time schedules and project milestones recommended by the contractor and approved by AFTAC. The work covered in Amendment 4, Tasks 1h et seq. should start by 1 December 1962 and continue for a period of approximately one year."

APPENDIX 2 to TECHNICAL REPORT NO. 63-99

DEEP WELL SITE REPORT

TERRY NO. 1 WELL, ORANGE COUNTY, FLORIDA

TECHNICAL REPORT NO. 63-88

DEEP WELL SITE REPORT
TERRY NO. 1 WELL, ORANGE COUNTY, FLORIDA

THE GEOTECHNICAL CORPORATION
3401 Shiloh Road
Garland, Texas

16 September 1963

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS, Continued

ILLUSTRATIONS, Continued

DEEP WELL SITE REPORT
TERRY NO. 1 WELL, ORANGE COUNTY, FLORIDA

ABSTRACT

The Terry No. 1 Deep Well in Orange County, Florida, has been prepared for use in a deep-well measurement program. The history and geology of the well are given. The deep well and surface instrumentation is described, typical recorded events are illustrated, and results of analysis of records are described.

DEEP WELL SITE REPORT
TERRY NO. 1 WELL, ORANGE COUNTY, FLORIDA

1. GEOLOGY AND HISTORY OF THE TERRY NO. 1 DEEP WELL

1.1 INTRODUCTION

The Terry No. 1 well was prepared for use in a deep-well measurement program as part of tasks 1h (1) and 1h (2) of the Statement of Work of Contract AF 33(600)-43369, Project VT/1139, Phase III.

1.2 WELL HISTORY

The well is situated in the north-central part of Orange County, Florida, about 15 miles southeast of the city of Orlando (see map, figure 1). It was originally drilled by Warren Petroleum Corporation as an exploratory test for oil and gas and was plugged and abandoned as a dry hole on September 13, 1955.

1.3 GEOLOGY OF THE AREA

Located in the east-central part of the Florida Peninsula, about 40 miles inland from the Atlantic coastline, the well is structurally situated on the southeast flank of the Ocala Uplift (see figures 2 and 3). Unconsolidated Quaternary sediments at the surface overlie the Ocala limestone of Eocene age. The well, originally drilled to a total depth of 6585 ft, is bottomed in crystalline rocks believed to be of Precambrian age.

A lithologic log has been constructed from sample descriptions, electrical logs, and microfossil interpretations; and a sonic-velocity log was conducted during well recompletion. The stratigraphic section penetrated, together with related interval velocities, is shown by figures 4 and 5.

1.4 WELL PREPARATION

Recompletion of the well as The Geotechnical Corporation No. 1 Terry was effected 24 April 1963. It was cleaned out to the original total depth of

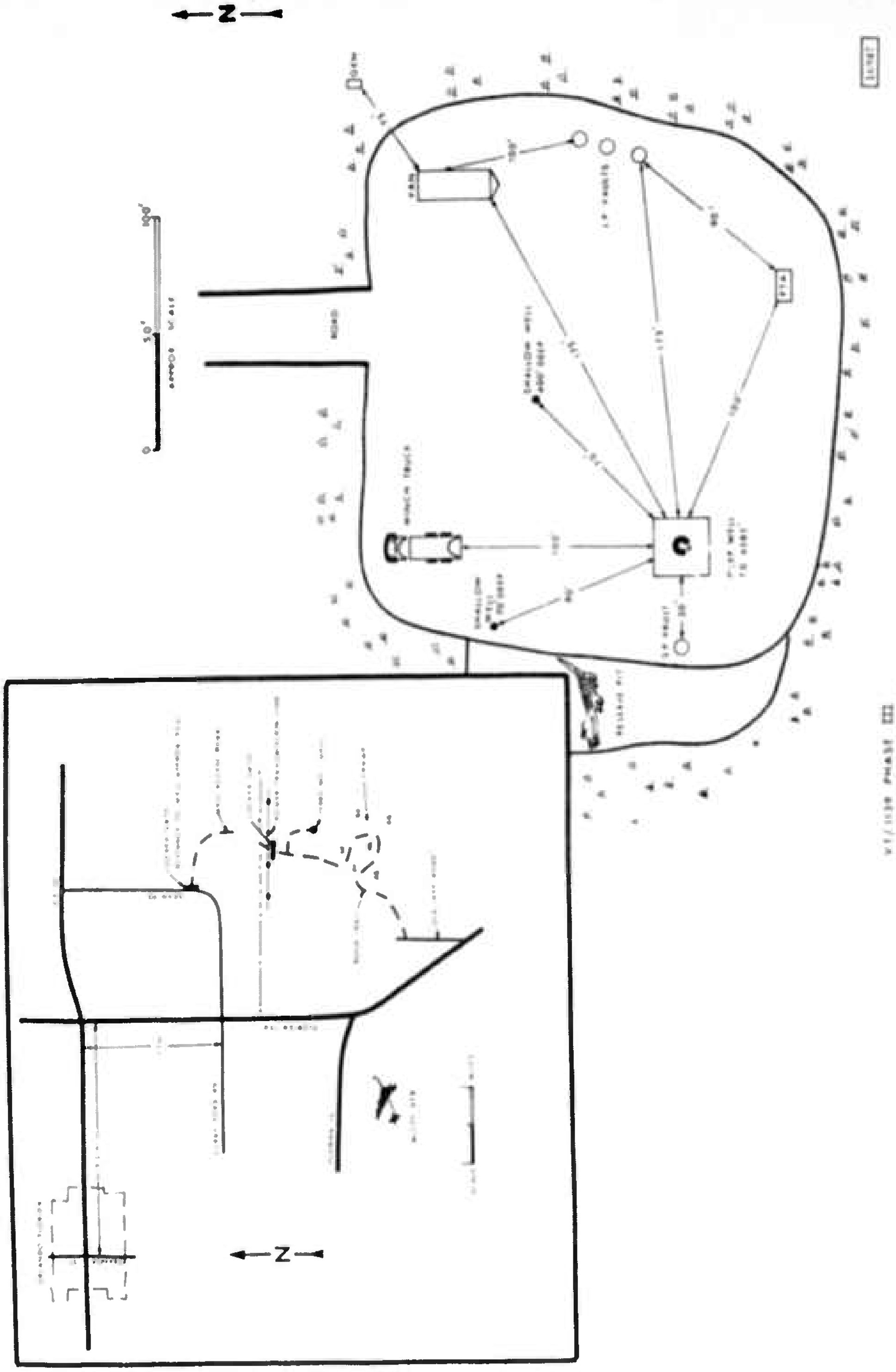


Figure 1. Site map, Terry No. 1

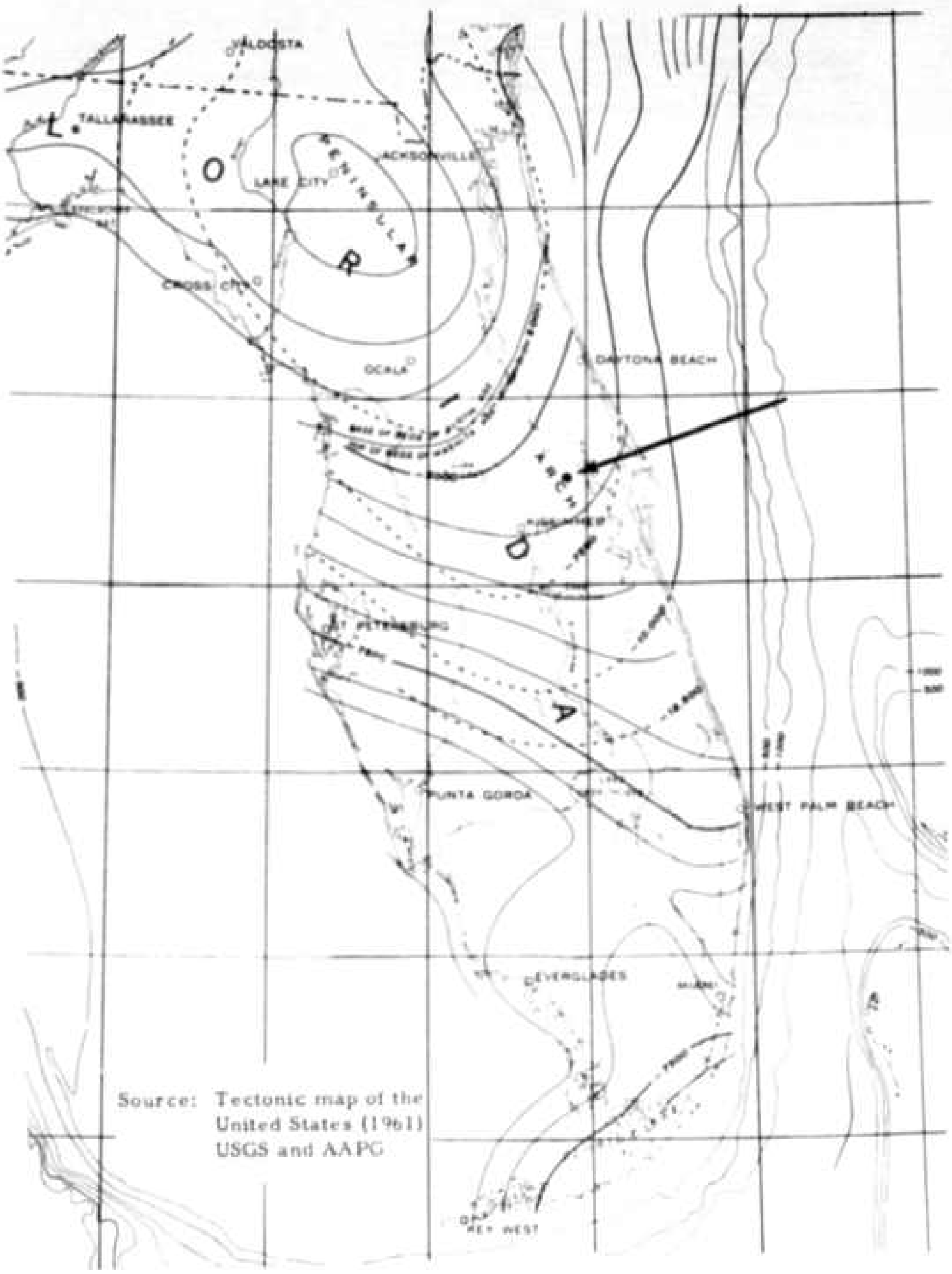
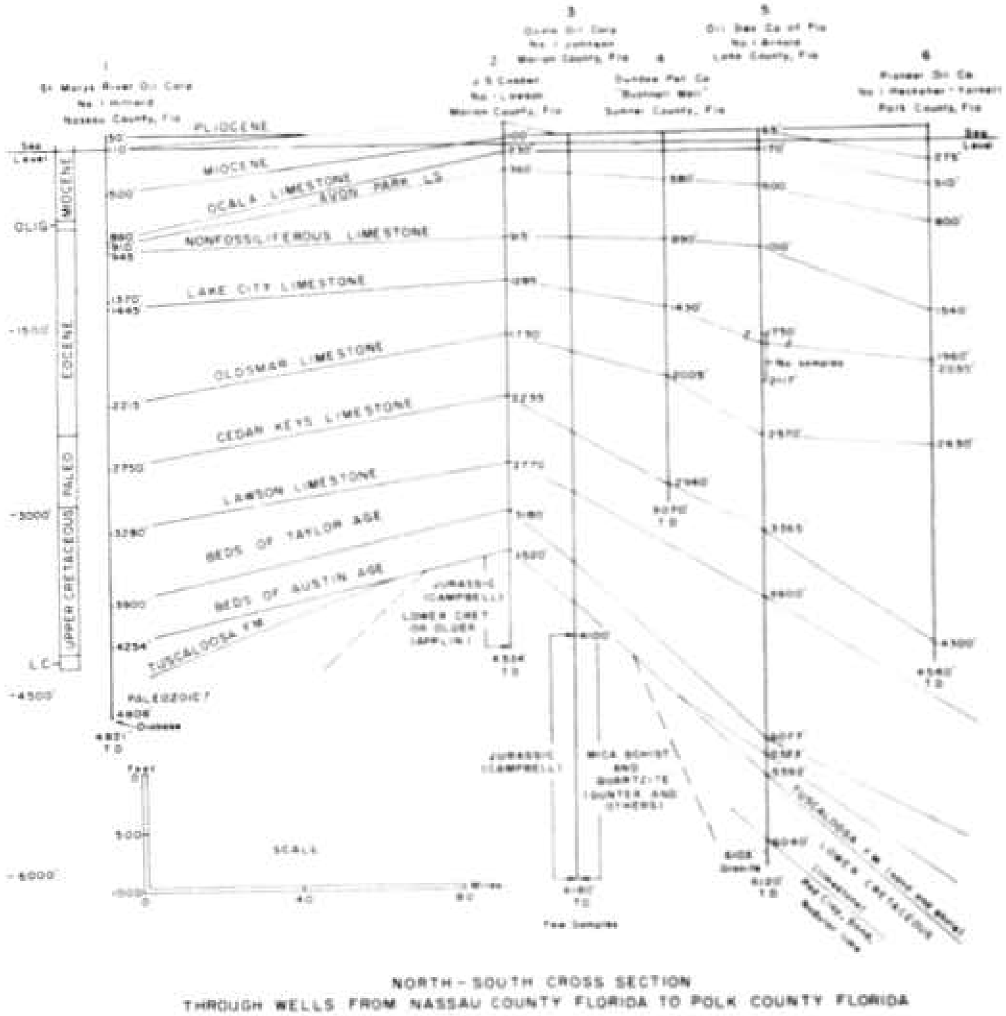


Figure 2. Map of tectonic environment, Terry No. 1



Source of cross section:
Applin, P. L., and Applin, E. R., 1944, Regional subsurface stratigraphy and structure of Florida and southern Georgia: Am. Assoc. Petroleum Geol. Bull., vol. 28, no. 12, p. 1673-1753

Figure 3. Geologic cross section, Ocala uplift

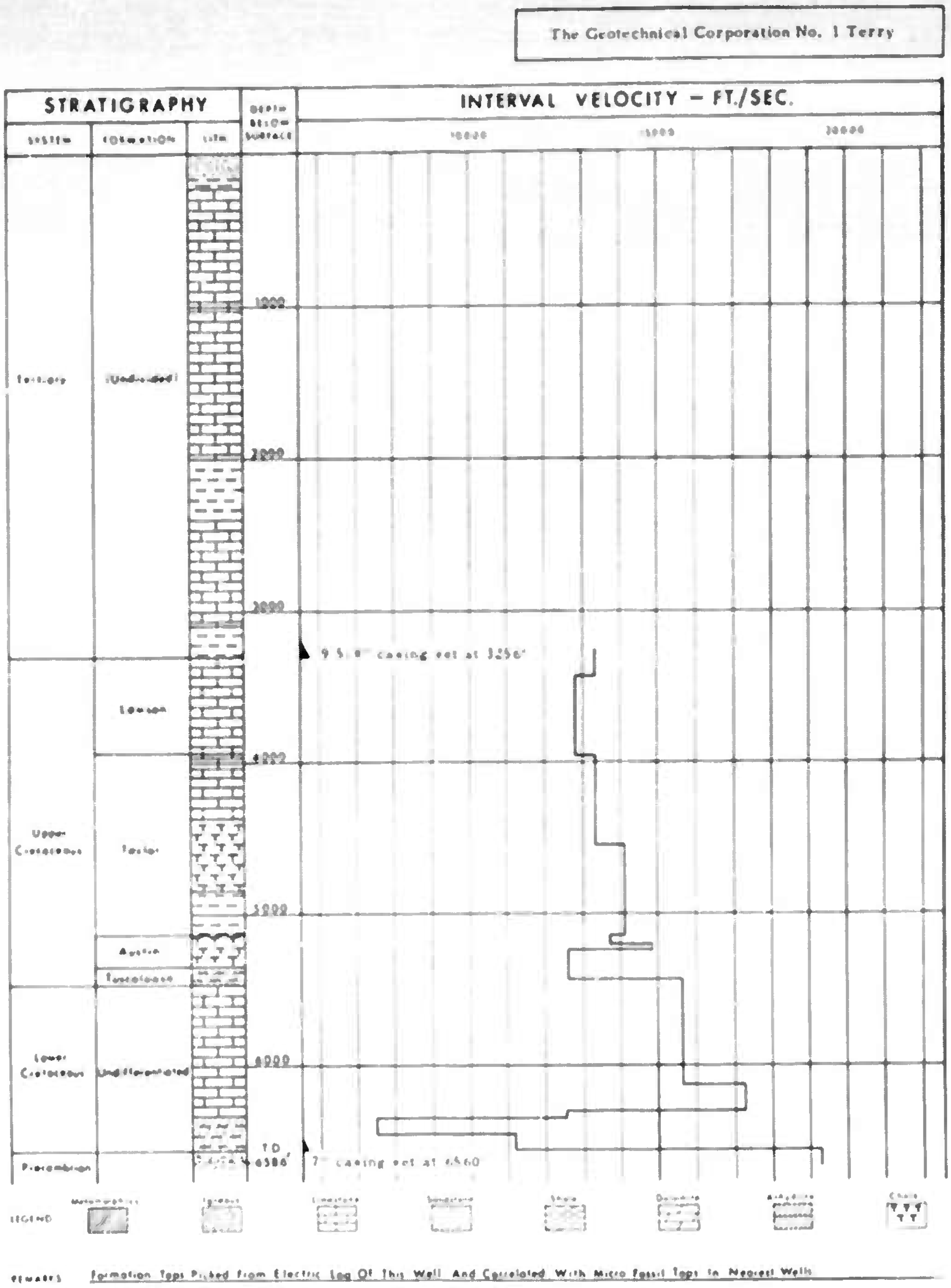


Figure 4. Stratigraphy and velocities, Terry No. 1

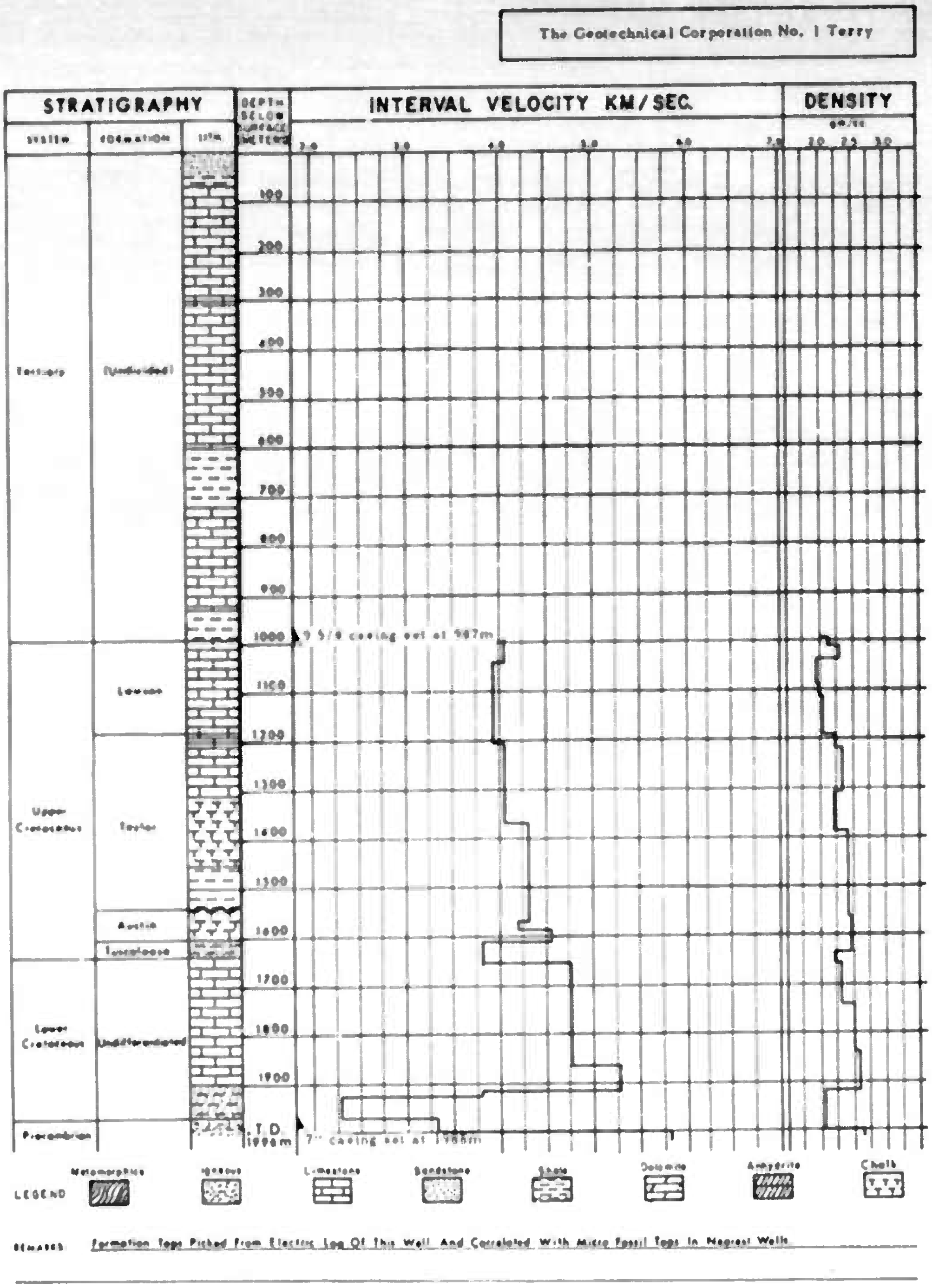


Figure 5. Stratigraphy and velocities (metric), Terry No. 1

6585 ft, and 7-in. casing was set below the top of the basement complex at 6560 ft and cemented with 680 sacks of cement. The casing plug was drilled out, thus achieving an operating environment of 25 ft of uncased hole in the crystalline basement complex. The top of the cement behind the casing is at a depth of approximately 3100 ft. (See figure 6.) All footage measurements are from 16 ft above permanent datum, which is the bradenhead flange located in the cellar, 3 ft below ground level. Maximum deviation of the hole from vertical is less than 5°. Maximum bottom hole temperature observed during sonic-velocity logging operations is 152° F.

The well is so completed that a seismometer may be optionally operated at the following positions.

a. On the bottom at 6585 ft in basement complex;

b. Anywhere in the 25 ft of open-hole penetration of the basement complex from 6585 ft to 6560 ft;

c. In the cased hole in the basement complex by locking in the casing shoe at 6560 ft;

d. In the cased hole at the approximate Lower Cretaceous/basement contact by locking in the casing float collar at 6549 ft; and

e. At any desired depth up the cased hole at intervals of approximately 30 ft at the casing collars.

Figure 7 shows the completed well site.

1.5 GENERAL

Detailed information on the site location and facilities is given in appendix 1.

2. MEASUREMENT PROGRAM AT THE TERRY NO. 1 DEEP WELL

2.1 INTRODUCTION

Measurements were made with surface instruments and with a deep-well seismometer operated at various depths in the well. The surface

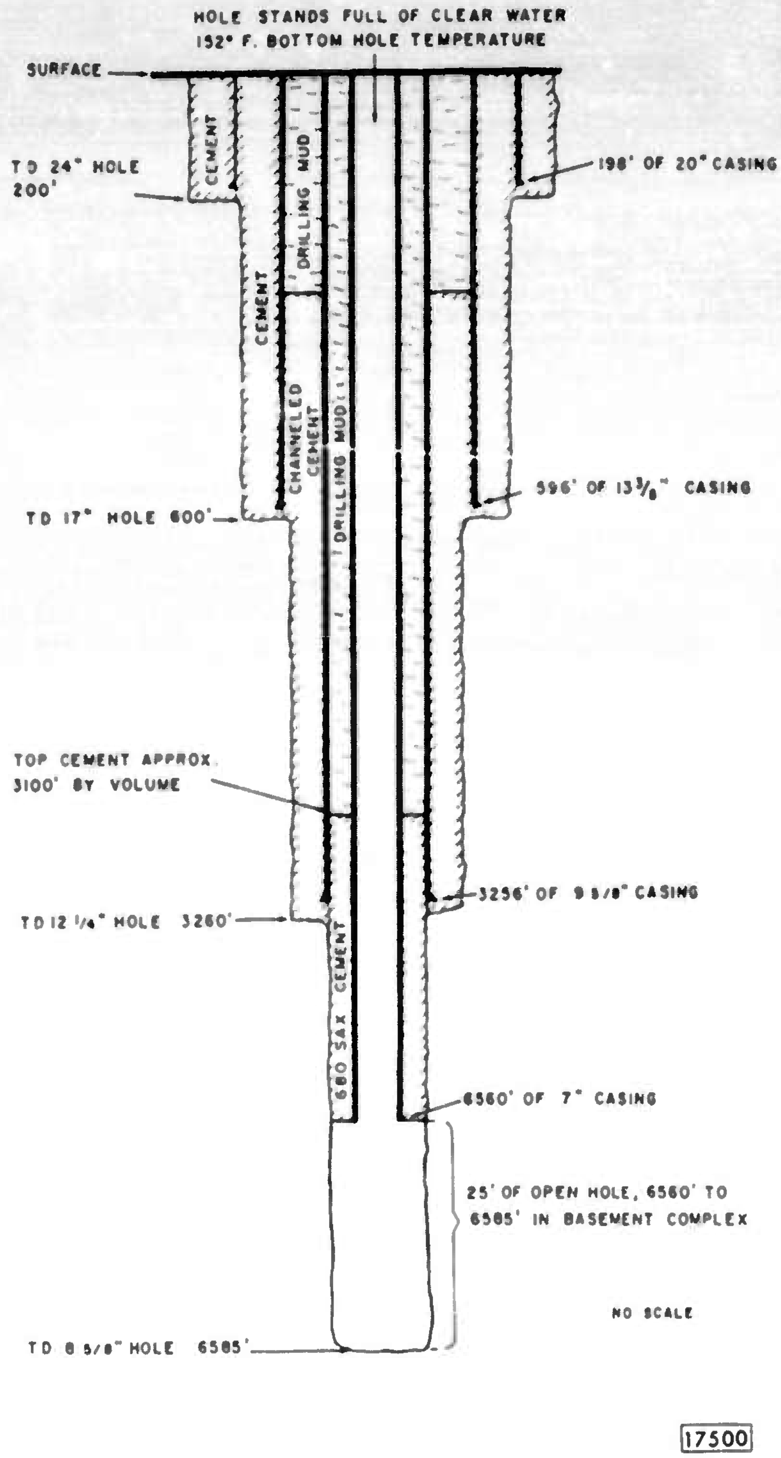


Figure 6. Casing diagram, Terry No. 1

Figure 7. Completed well site, Terry No. 1

instrumentation consisted of a recording van and associated equipment, short-period and long-period seismometers, and phototube amplifiers. The recording van and surface instruments were provided by Contract AF 33(600)-41694 and are identical with the equipment used in the Long-Range Seismic Measurements Program (LRSM), except that a film recorder was added to the van to provide additional recording capability.

2.2 INSTRUMENTATION

Figure 8 shows the basic components of the deep-well seismograph. Figure 9 shows a block diagram of the LRSM system, including long-period instrumentation. The deep-well and short-period surface systems are similar in their response. Each system uses a seismometer with an undamped natural frequency of 1 cps and a phototube amplifier using a 5 cps galvanometer. The surface and deep-well seismometers include provisions for remote calibration, thus allowing their responses to be verified. The calibration is accomplished by applying measured currents at various frequencies to the internal calibrators and recording the resultant output of the system. The output of the phototube amplifiers is connected to the recorders through attenuators so that the amplitudes of tne records may be adjusted as desired.

The film recorder which was added to the van is a 16-channel automatic processing device which makes visual records on 16-mm film. The magnetic tape recorder has provisions for 16 channels of data, and the Mark II recorders provide 4 channels each on 35-mm film. The film recorders also record station time, and radio station WWV is recorded on one channel of the magnetic tape recorder.

A control device is used to permit control of the various functions of the deep-well seismometer. These functions include the calibration mentioned above, locking, unlocking, and centering of the mass, and operation of a hole lock to secure the seismometer to the well casing at any selected casing collar.

2.3 RECORDS AND SYSTEM RESPONSE

Figures 10 and 11 show events recorded in the well. Figures 12 and 13 show the response of the seismographs to steady-state calibration frequencies.

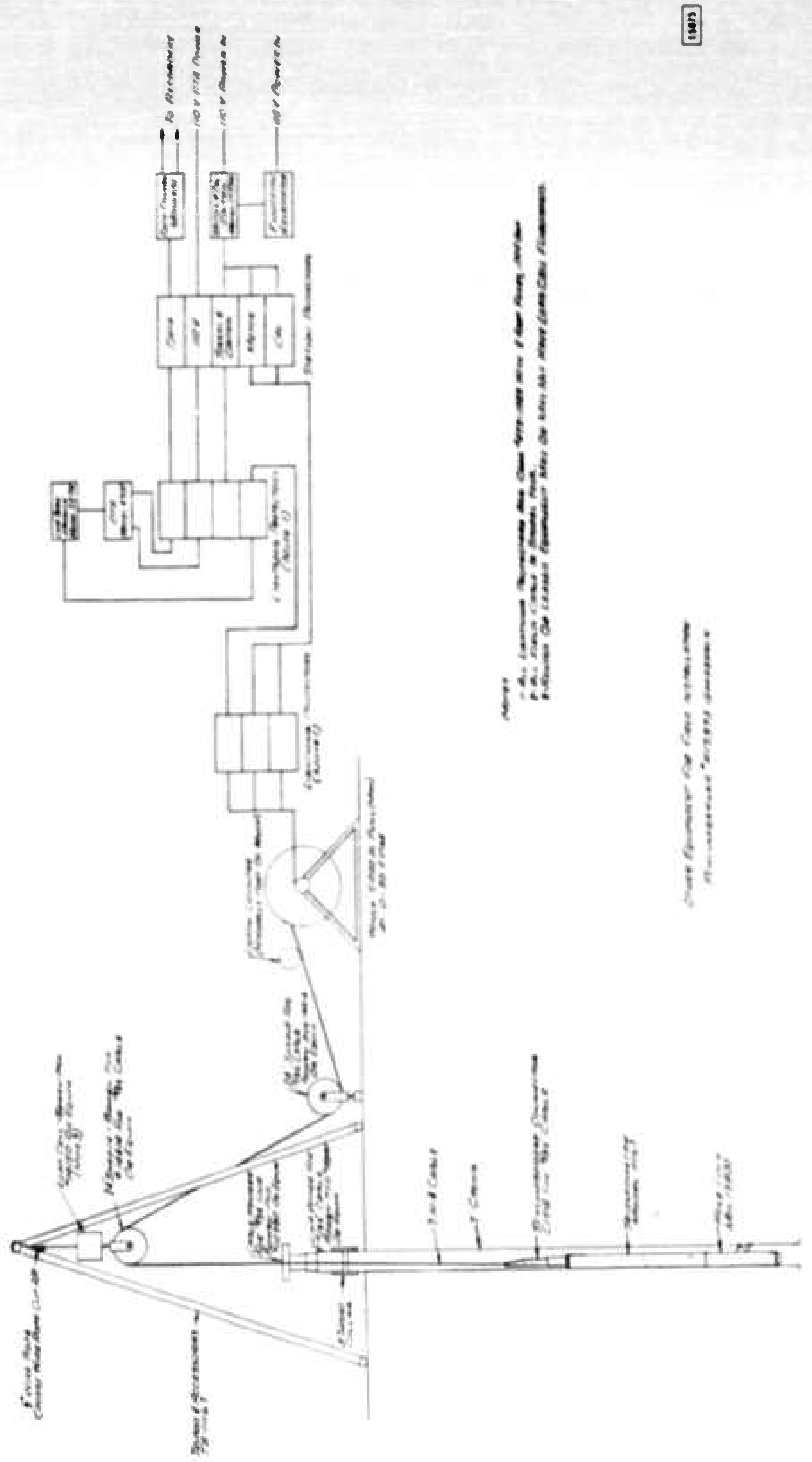


Figure 8. Deep-well Seismograph System, Model 15075

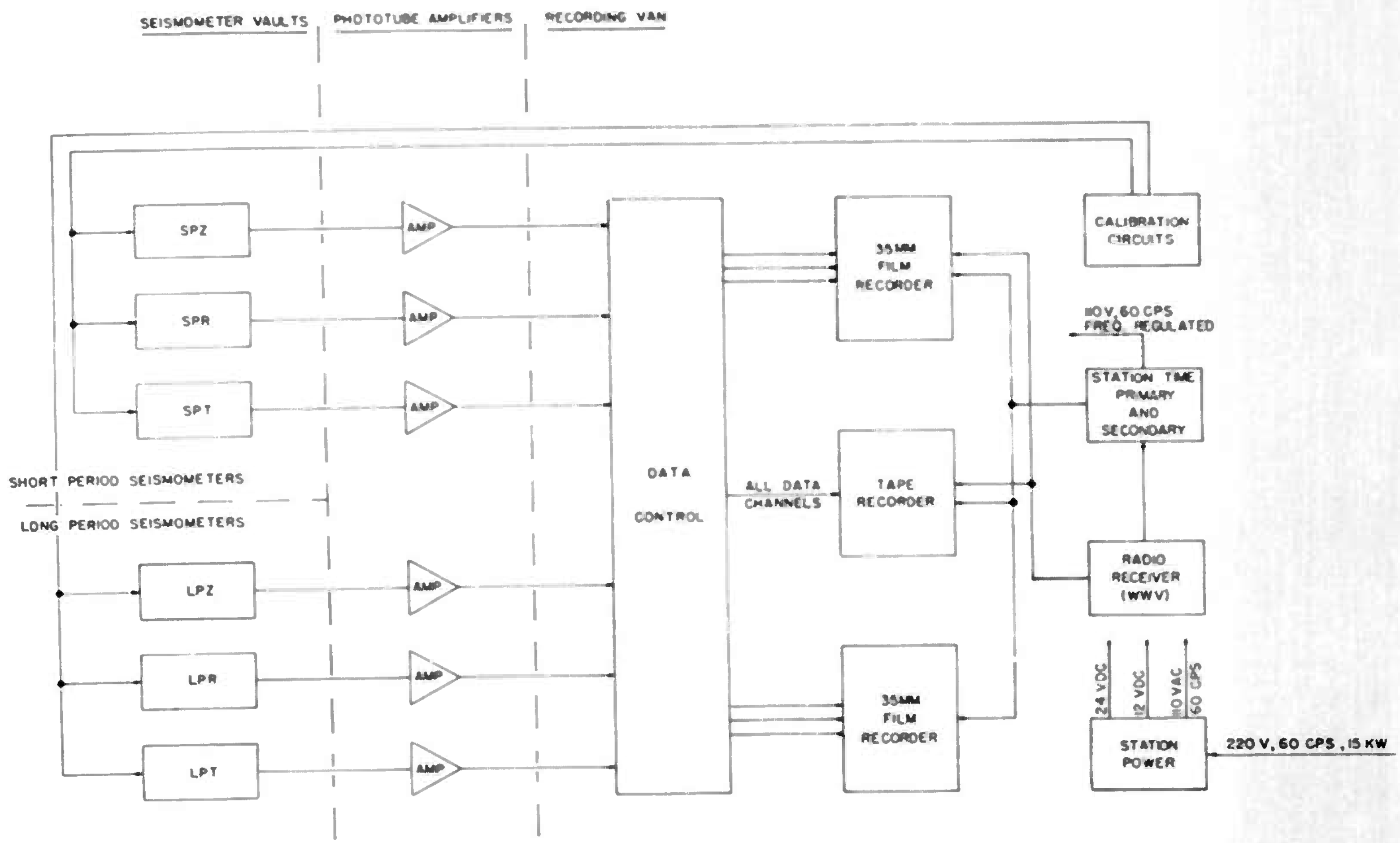


Figure 9. Simplified block diagram of the LRSM seismograph system

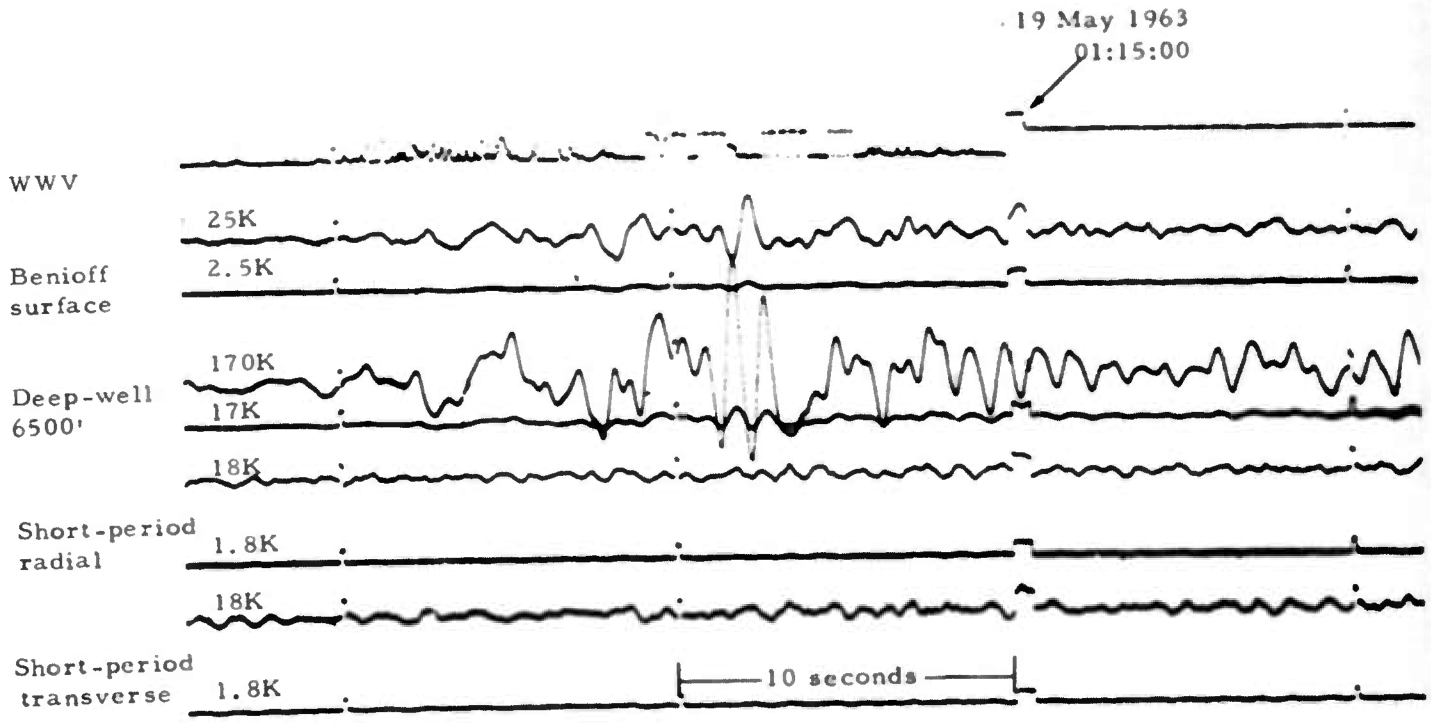


Figure 10. Develocorder record of small Benioff, deep-well, short-period radial, and short-period transverse seismometers at Orlando, Florida. Magnification at 1 cps, X10 view. Event from coast of southern Chile, Δ approximately 78°, depth about 33 km, m = 6.5.

69

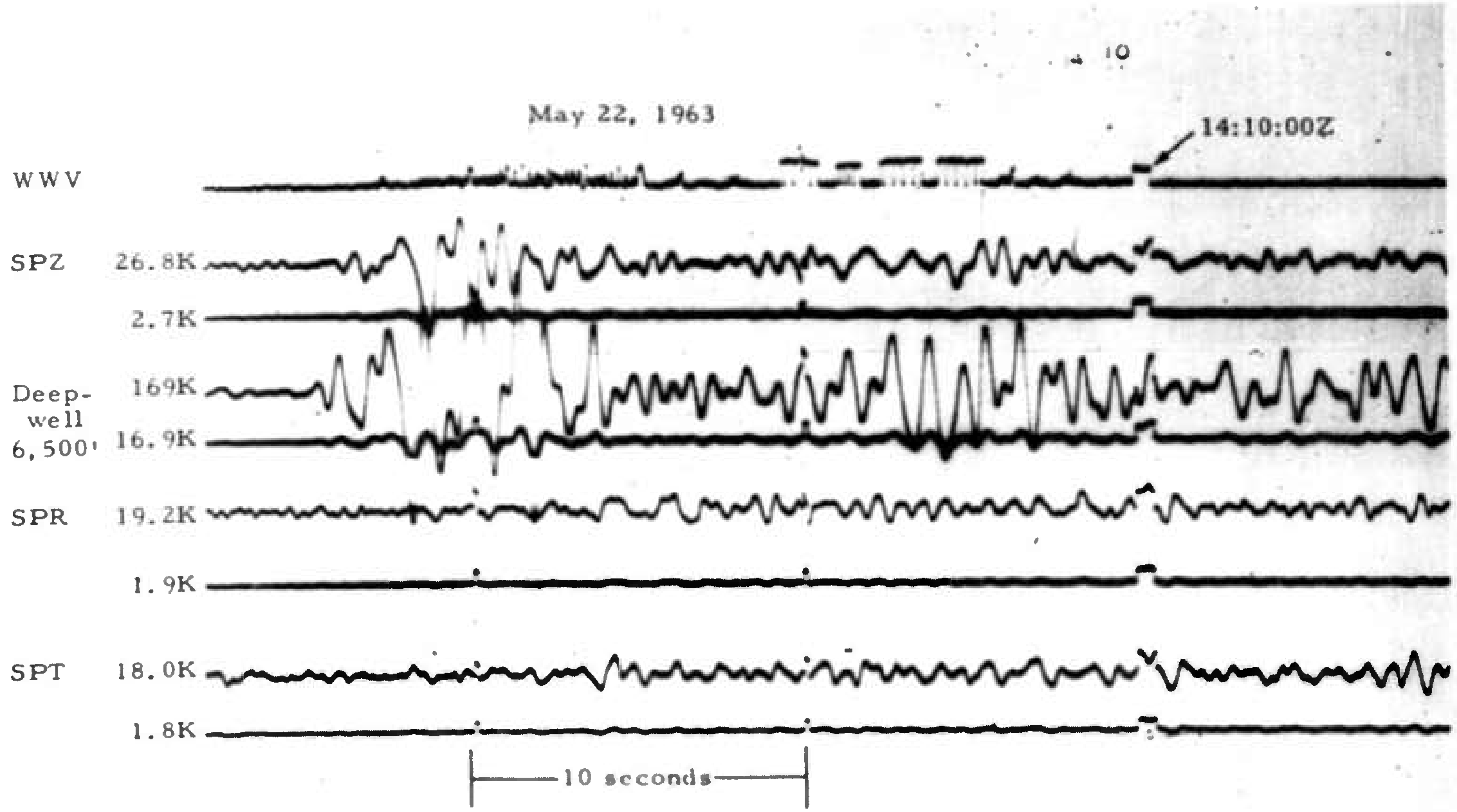


Figure 11. Develocorder record of small Benioff, deep-well and horizontal Benioff seismometers at Orlando, Florida. Magnification at 1 cps, X10 view.

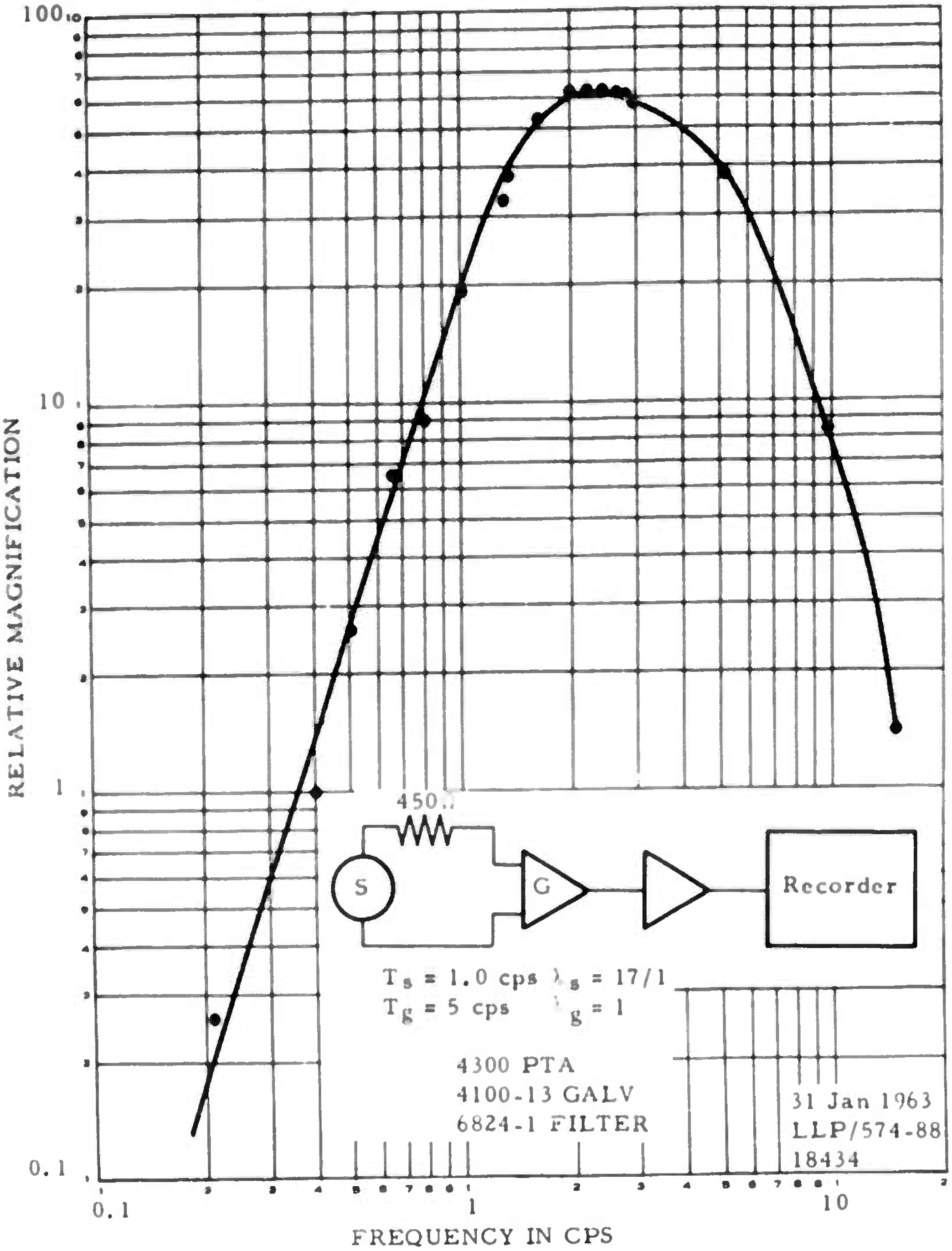


Figure 12. Frequency response of deep-well seismograph

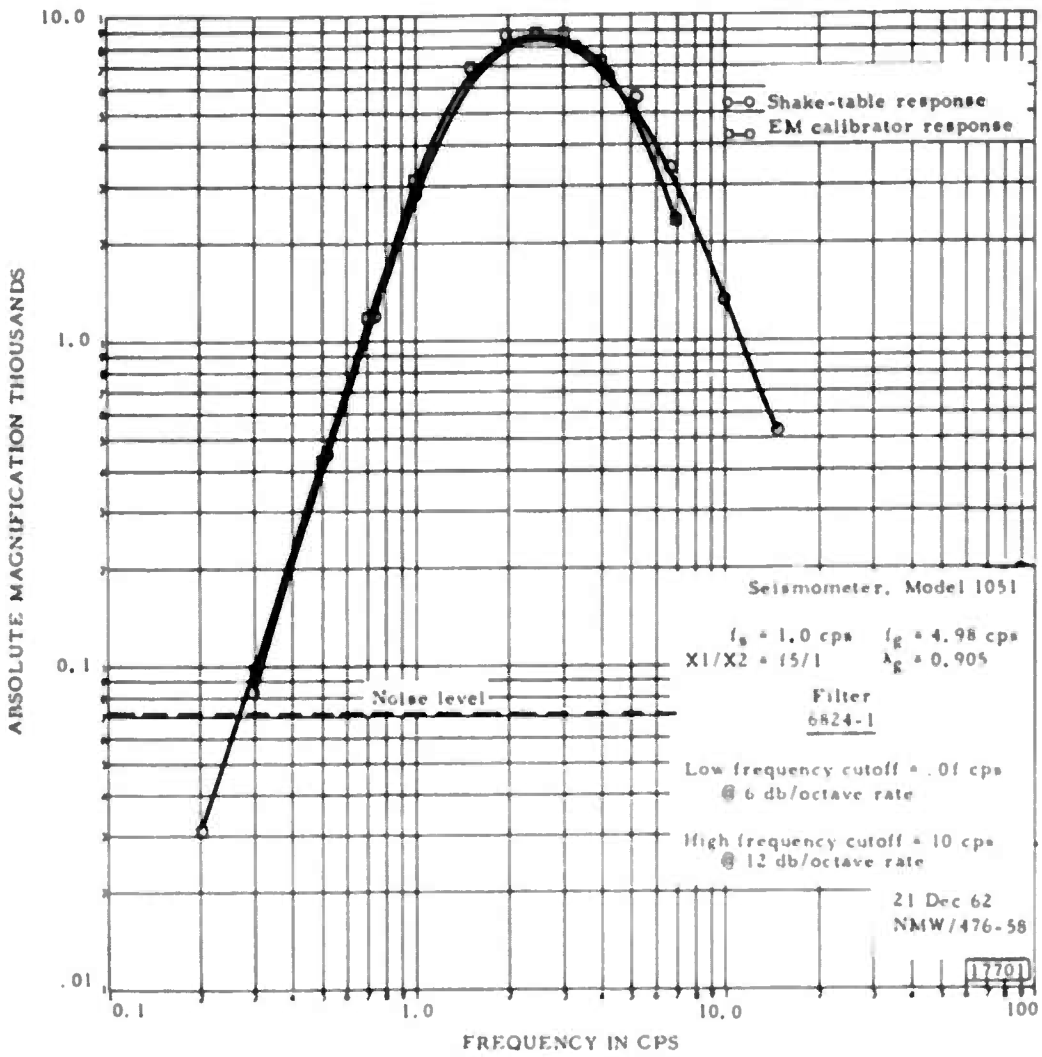


Figure 13. Frequency response of the short-period seismograph, from shake-table and electromagnetic calibrator tests

3. DATA ANALYSIS

3.1 INTRODUCTION

The No. 1 Terry well reaches a total depth of 6585 ft and penetrates the basement. The section is composed mainly of high-velocity limestones, in which the amplitude of surface waves is not expected to decrease as rapidly as in a low-velocity section.

Because of proximity to the ocean, the noise background is rather large for the longer periods (0.8 to 1.5 sec) in the passband of interest (0.3 to 1.5 sec). The surface instruments are located on unconsolidated material which is very sensitive to local vibrations; high frequency noise predominates on the surface records when the wind is blowing or when cultural activity is high in the vicinity.

The noise background at the site is abnormally variable, probably due to seasonal and diurnal changes in the sources responsible for the noise.

The well casing is cemented from 3100 ft to the bottom, and coupling between ground and seismometer is good. Above 3100 ft, the casing is not cemented in place, and coupling may be poor as was demonstrated during experiments at Grapevine, Texas.

The theoretical results included in the data analysis were obtained from the Data Analysis and Technique Development Center in Alexandria, Virginia.

3.2 METHOD OF MEASURING NOISE

The noise distribution curves given in the report were obtained by measuring the largest noise amplitude present in the 10-sec interval immediately following a 5-min mark.

The amplitudes were not corrected for instrument response, and the magnifications at 1 cps were used to obtain the millimicron (mμ) values given. Samples were taken during times when the cultural activity in the vicinity was minimum; 100 samples were taken at each depth. All measurements of amplitude were peak-to-peak.

This method of measuring the noise essentially defines the detection capability of the site. The results are given as "probability of occurrence" curves

which determine the probability that a noise pulse of the same amplitude as a signal will occur at approximately the same time. The slope of the curve gives a measure of the variability of the noise amplitudes.

The periods of the pulses measured are also plotted to allow a comparison of the periods predominant at each depth.

The method has the advantage of ease of measurement and gives consistent, reproducible results by visual analysis; however, it should not be taken as a substitute for spectral analysis of the noise.

The probability of occurrence curves give a good picture of the decrease in noise level in the deep well without making any attempt to distinguish between the decay of the different frequencies which occur in the noise.

3.3 NOISE ANALYSIS

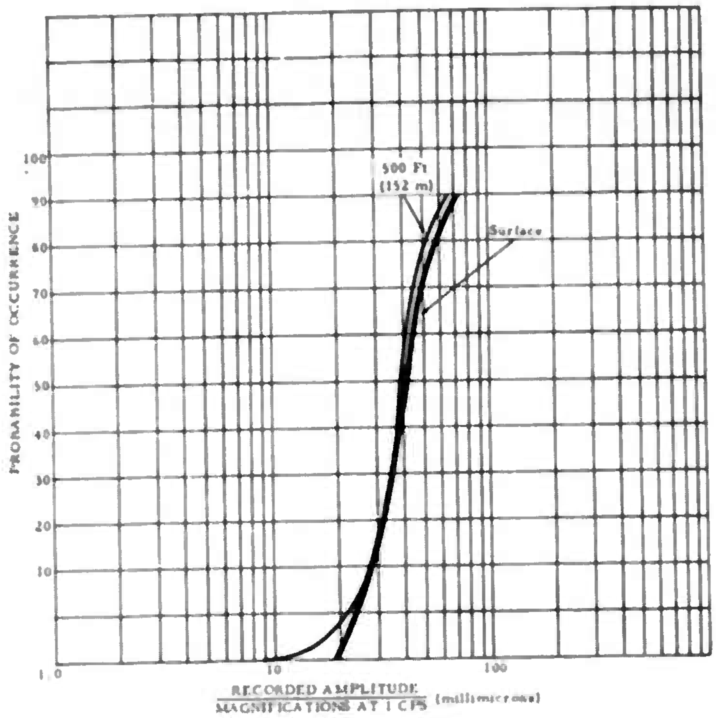
Figures 14 through 21 show the probability of occurrence and the frequency distribution curves for the different depths at which the deep-well seismometer was operated at Orlando, Florida.

The surface noise is extremely variable, mainly due to the variability in the cultural high-frequency (0.3 to 0.5 sec) noise; however, from the deep-well results it can be seen that the longer period (0.8 to 1.5 sec) noise is also rather variable. Changes of as much as 25% in average noise amplitude have been observed in 24 hours.

With one seismometer in the deep well, measurements can be obtained at only one depth at a time, and the variability in the results cannot be avoided. Noise measurements were made at times when the high-frequency noise at the surface was at a minimum to facilitate the measurement of the longer periods which govern the improvement possible at depth.

Figure 22 shows a plot of the 50% probability of occurrence level at each depth together with the P wave velocity section in the well. There appears to be no simple relationship between the velocities in the well and the decrease of the noise with depth.

Figure 23 shows the noise-amplitude attenuation with depth of Rayleigh waves compared to the theoretical results for the fundamental at 0.5, 1.0, and 2.0 sec and first higher mode waves at 1.0 sec. The theoretical results given



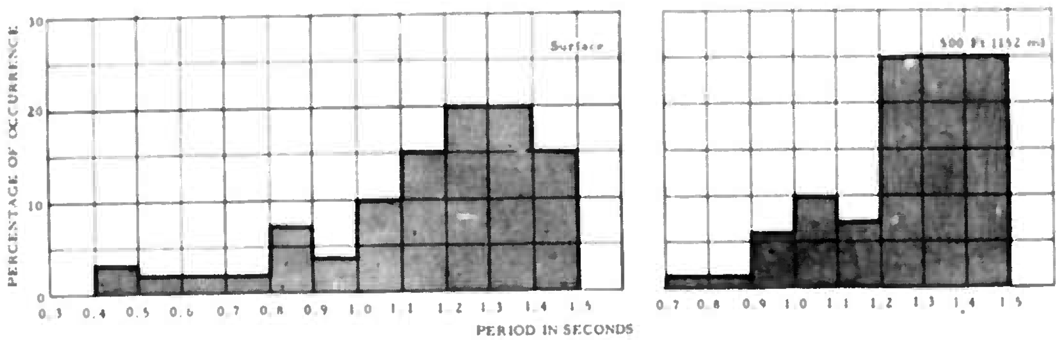


Figure 14. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 500 ft (152 m) in the deep well, Orlando, Florida

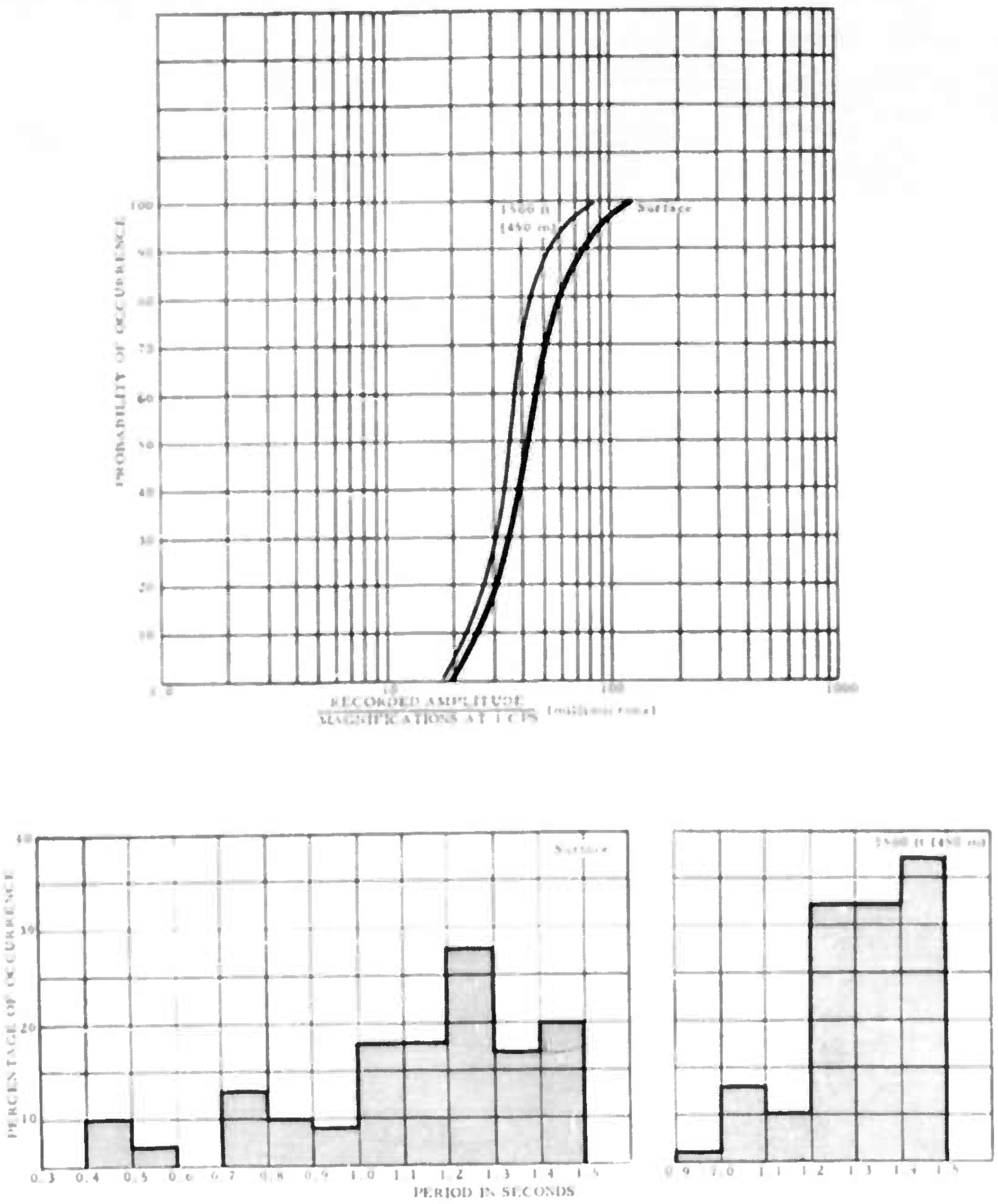


Figure 15. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 1500 ft (450 m) in the deep well, Orlando, Florida

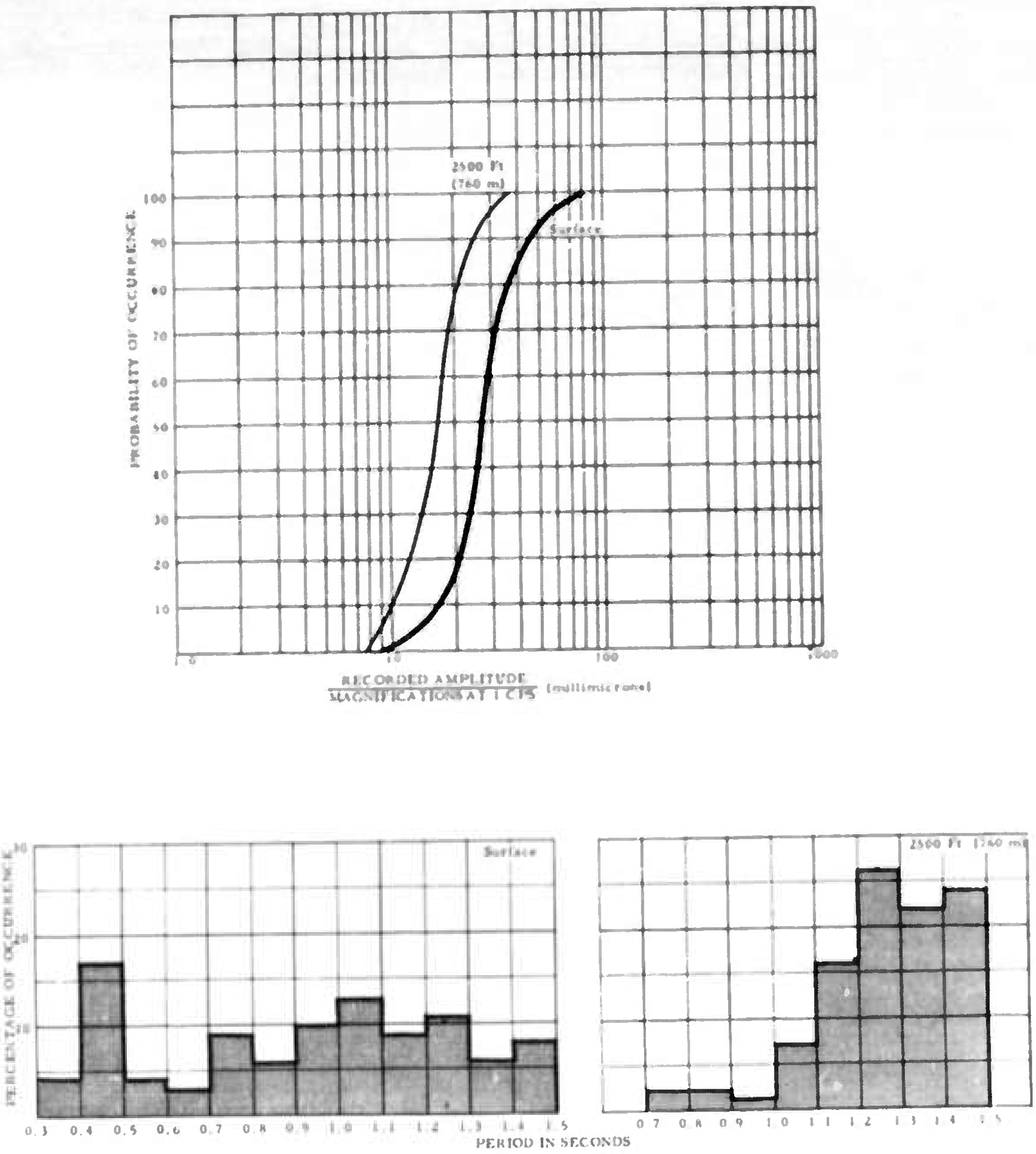
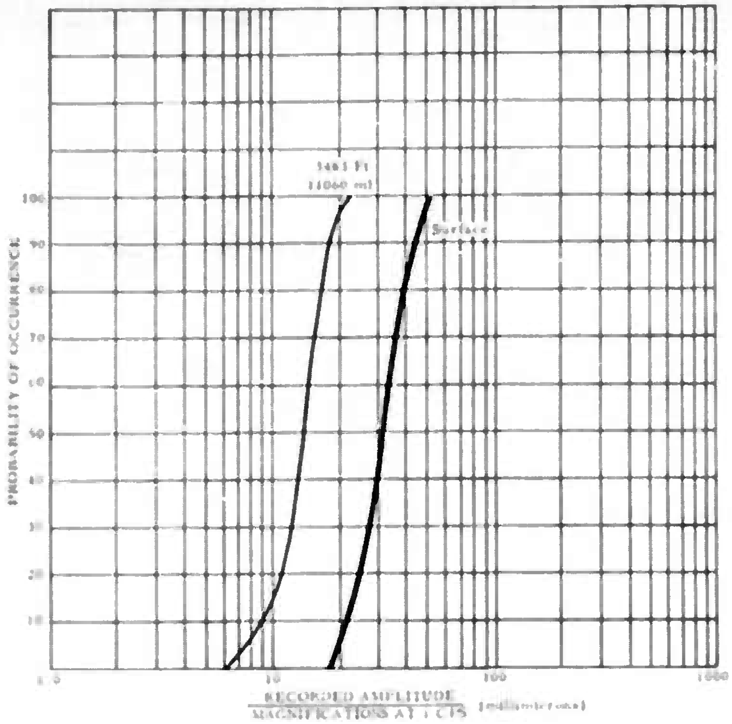


Figure 16. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 2500 ft (760 m) in the deep well, Orlando, Florida



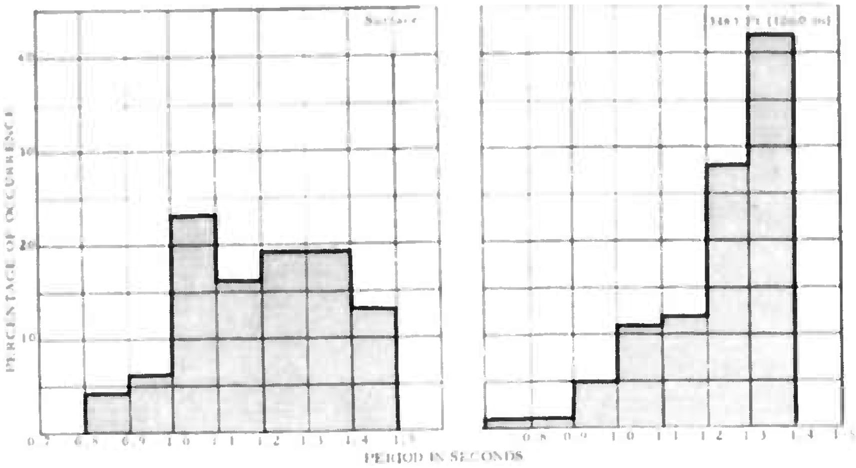


Figure 17. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 3483 ft (1060 m) in the deep well, Orlando, Florida

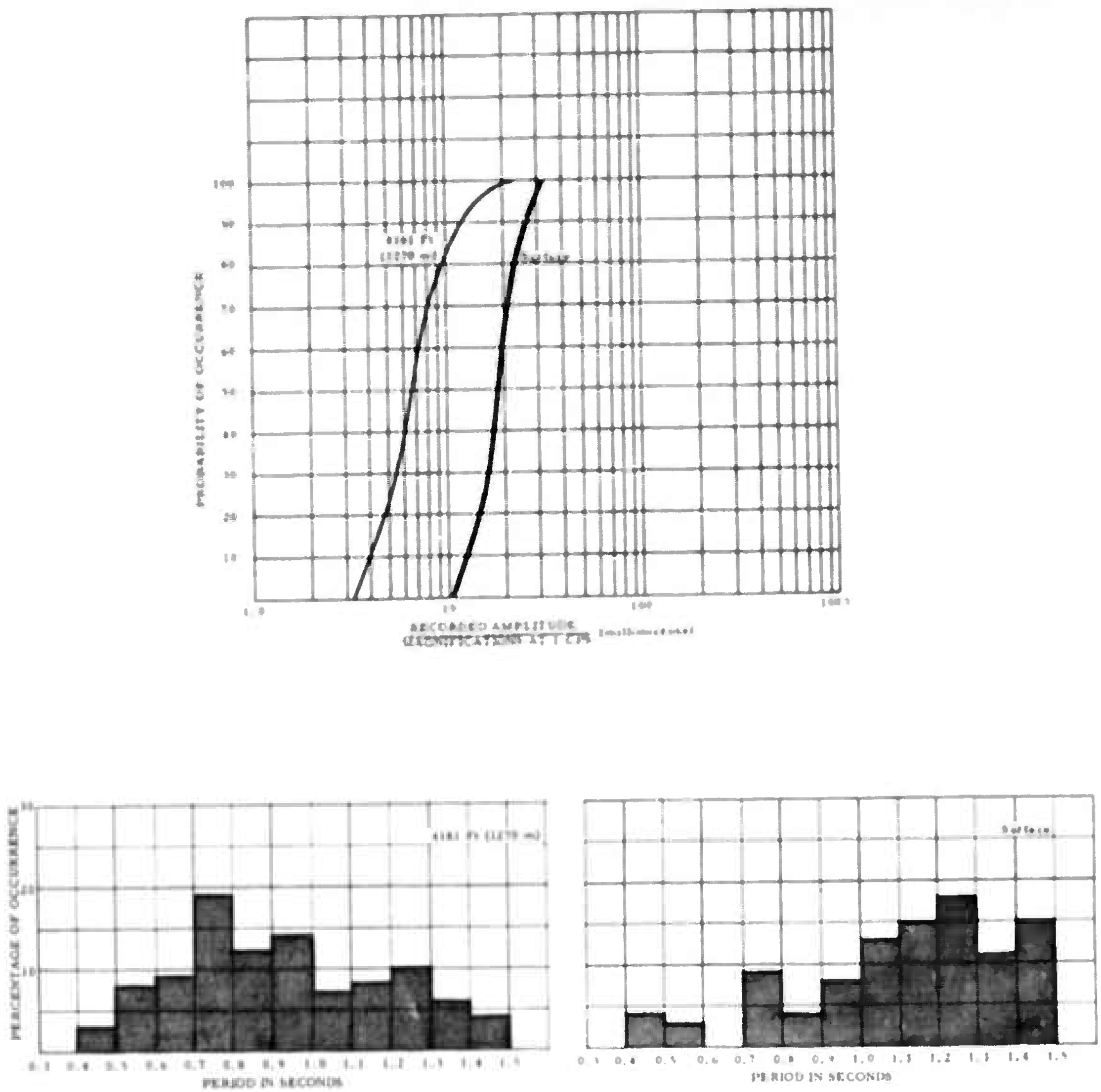


Figure 18. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 4181 ft (1270 m) in the deep well, Orlando, Florida

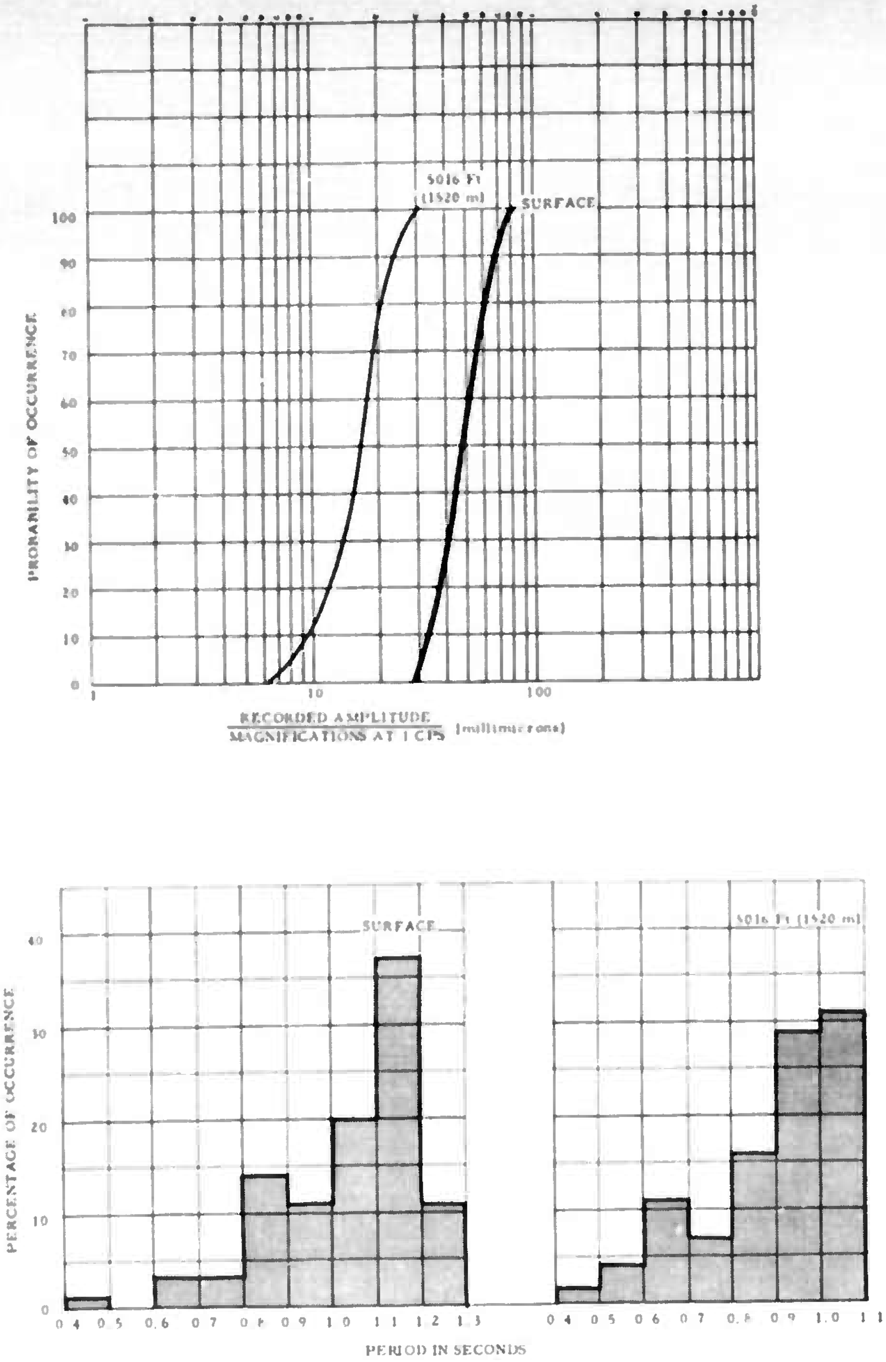
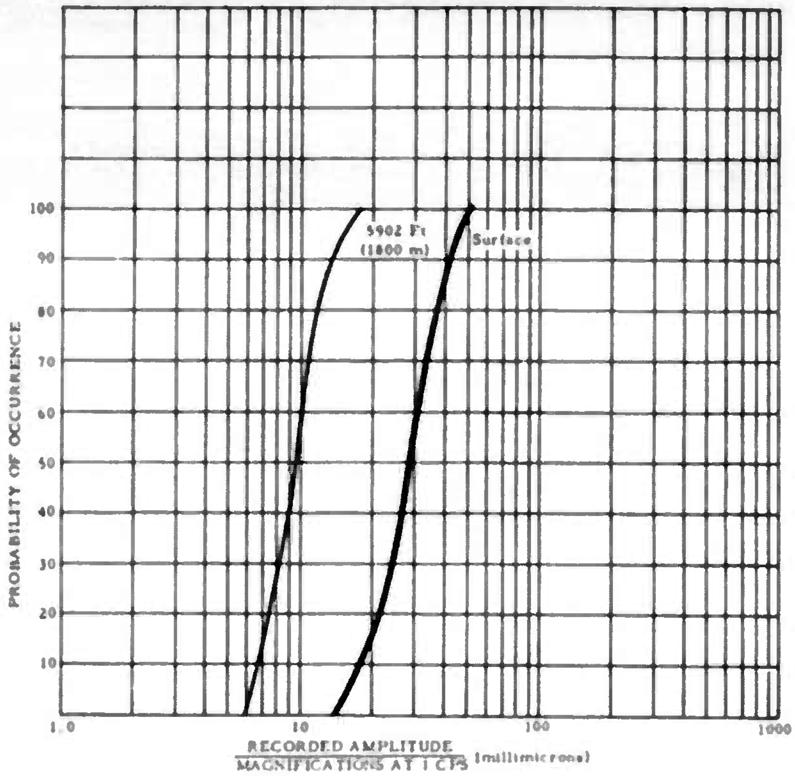


Figure 19. Distribution curves and histograms of the 0.3- to 1.5-sec noise at the surface and at 5016 ft (1520 m) in the deep well, Orlando, Florida



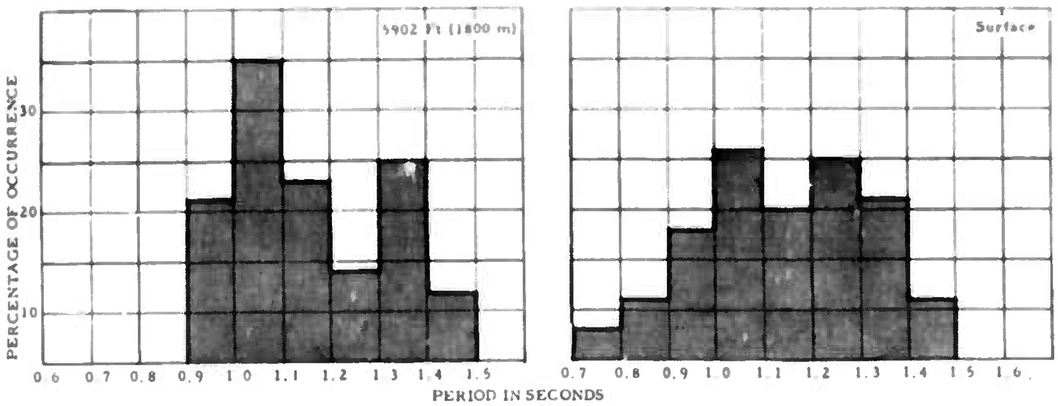
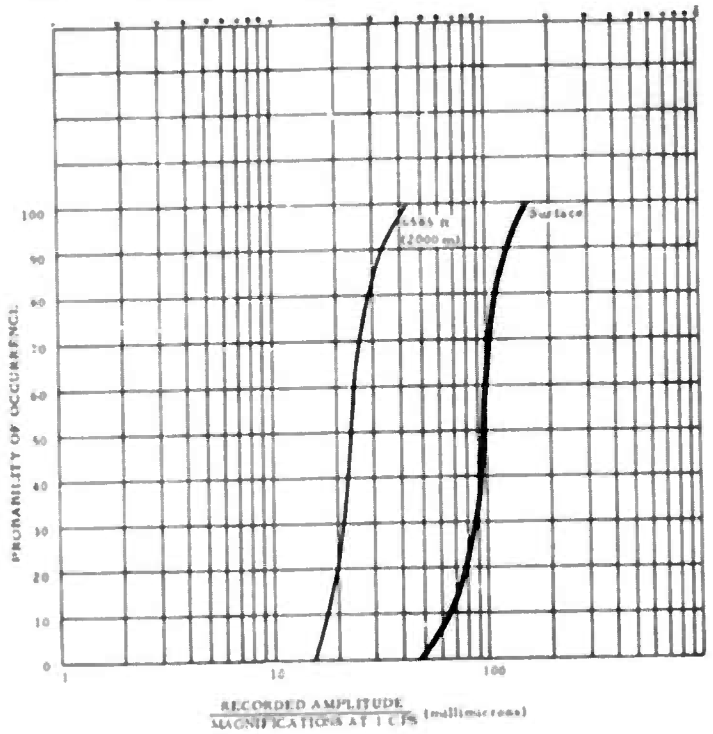


Figure 20. Distribution curves and histograms for the 0.3- to 1.5-sec noise at the surface and at 5902 ft (1800 m) in the deep well, Orlando, Florida



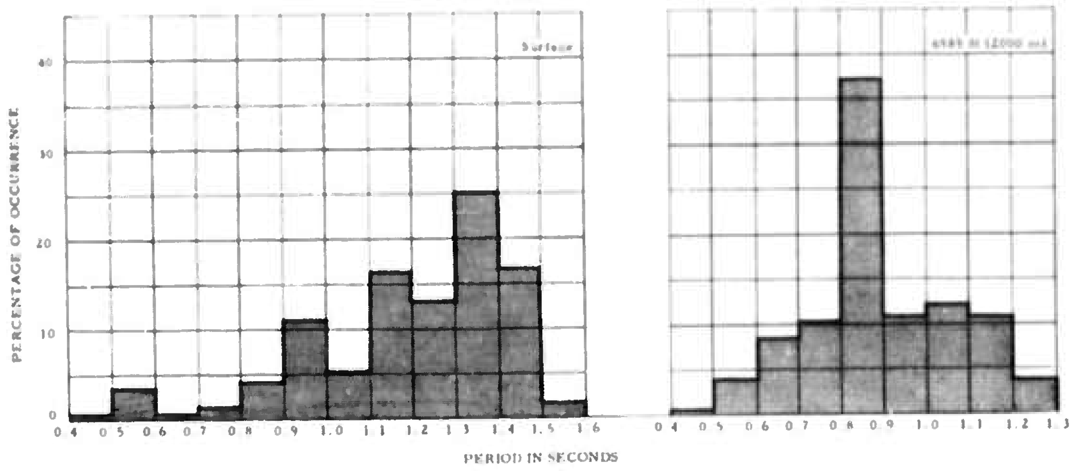


Figure 21. Distribution curves and histograms of the 0.3- to 1.5-sec noise at the surface and at 6585 ft (2000 m) in the deep well, Orlando, Florida

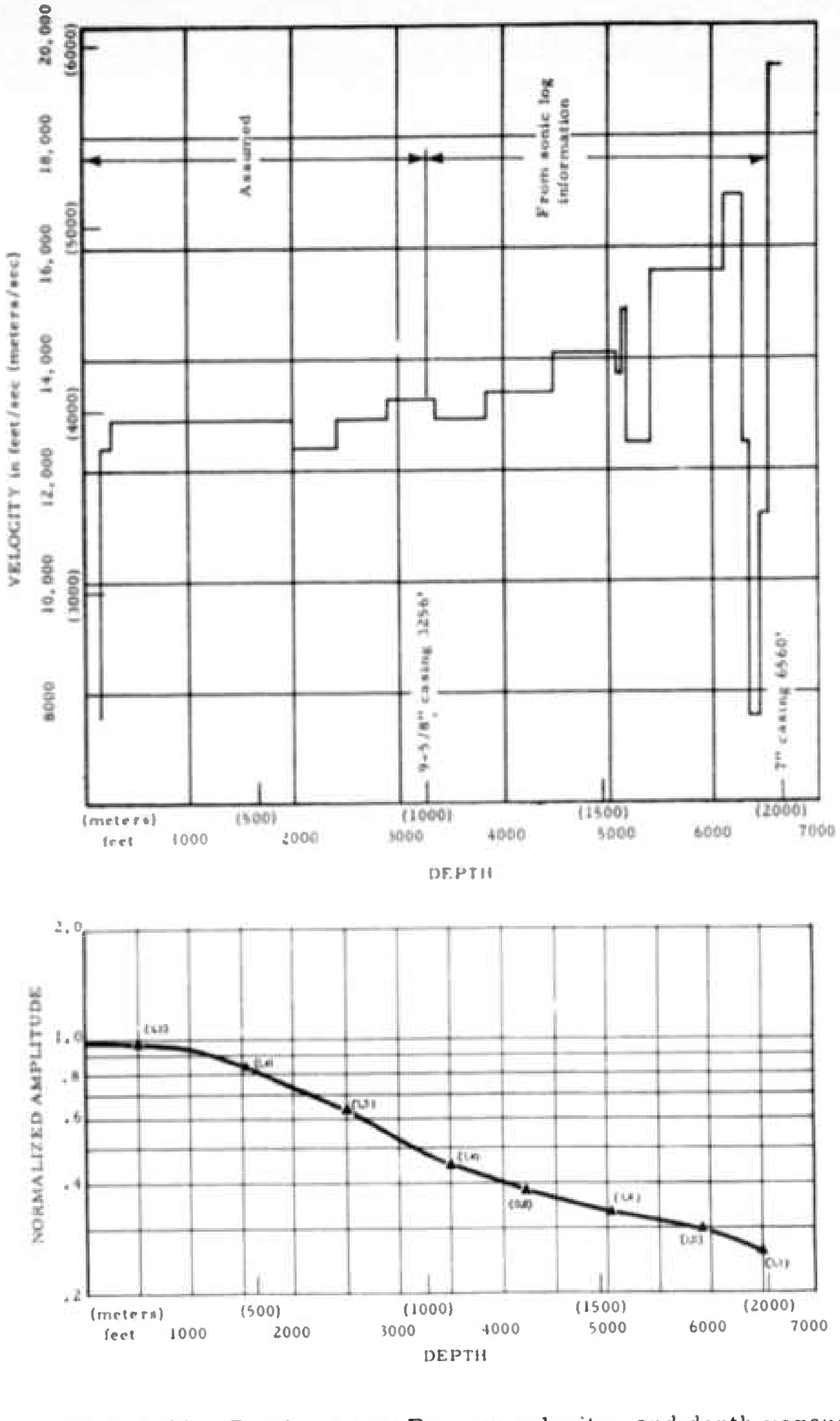


Figure 22. Depth versus P-wave velocity, and depth versus noise amplitude, Orlando, Florida

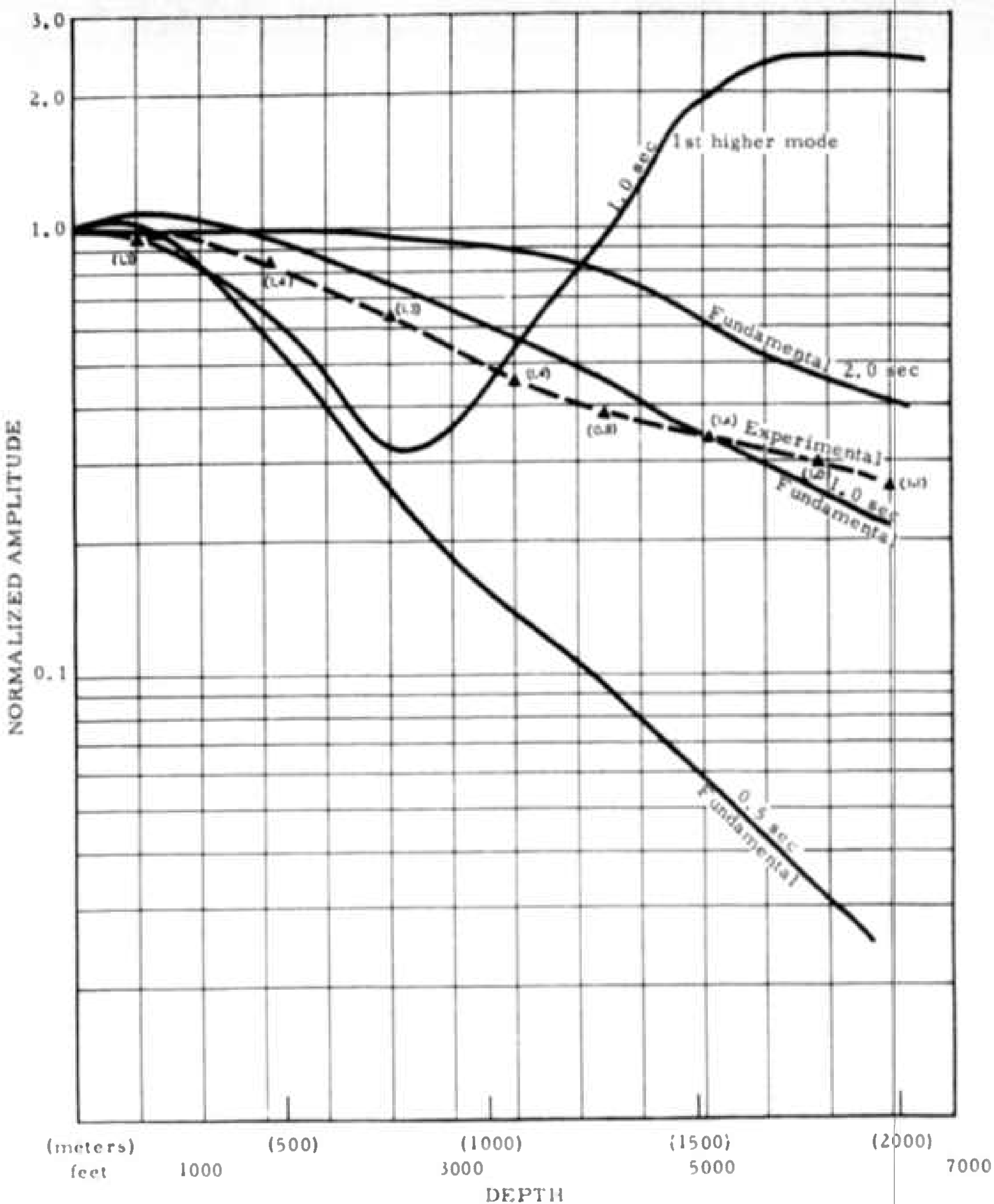


Figure 23. Plot of the theoretical Rayleigh wave amplitude decay with depth together with the experimental results obtained. Predominant noise period in parenthesis

here are calculated assuming a Ricker pulse with a center frequency at the frequency given extending over approximately one octave.

The main period encountered in the noise at various depths is given beside each experimental data point. In general, the predominant periods are 1.3 and 1.4 sec; however, at several depths shorter periods are predominant. It must be remembered that measurement of the noise by visual means is not very accurate. In general, the noise decays approximately as would be expected if the fundamental mode Rayleigh wave predominated in the noise.

Evidence for the first higher mode can sometimes be found in the noise. This mode is characterized by a 180° phase shift between the surface and depths below 2700 ft. A noise sample with suspected first higher mode Rayleigh waves is shown in figure 24.

The shift toward the shorter periods with depth that is evident at 5902 and 6585 ft may be due to the presence of first higher mode noise. However, evidence for first higher mode noise at Orlando of sufficient amplitude and duration to influence the results is not available at present.

Spectrum analysis of the records may provide an answer to the problem of the existence of higher modes at this site.

Operation of the deep-well seismometer in the open hole at bottom and in the cased hole right above the bottom did not reveal any difference in the noise levels. Spectrum analyses may show differences.

3.4 SIGNAL ANALYSIS

In attempting to determine the signal-to-noise improvement obtained at depth in deep wells, the decrease of P-wave signal amplitude with depth must be examined as well as the decrease in the noise amplitude.

At the No. 1 Terry well, 44 teleseismic signals of sufficient amplitude to be used for analysis were obtained. The amplitudes of the P waves were measured from the first cycle at both surface and at depth to avoid the interference caused by the surface reflection in the deep well.

Figure 25 shows the decrease in signal amplitude with depth. The points were obtained by averaging over all the events received at each depth.

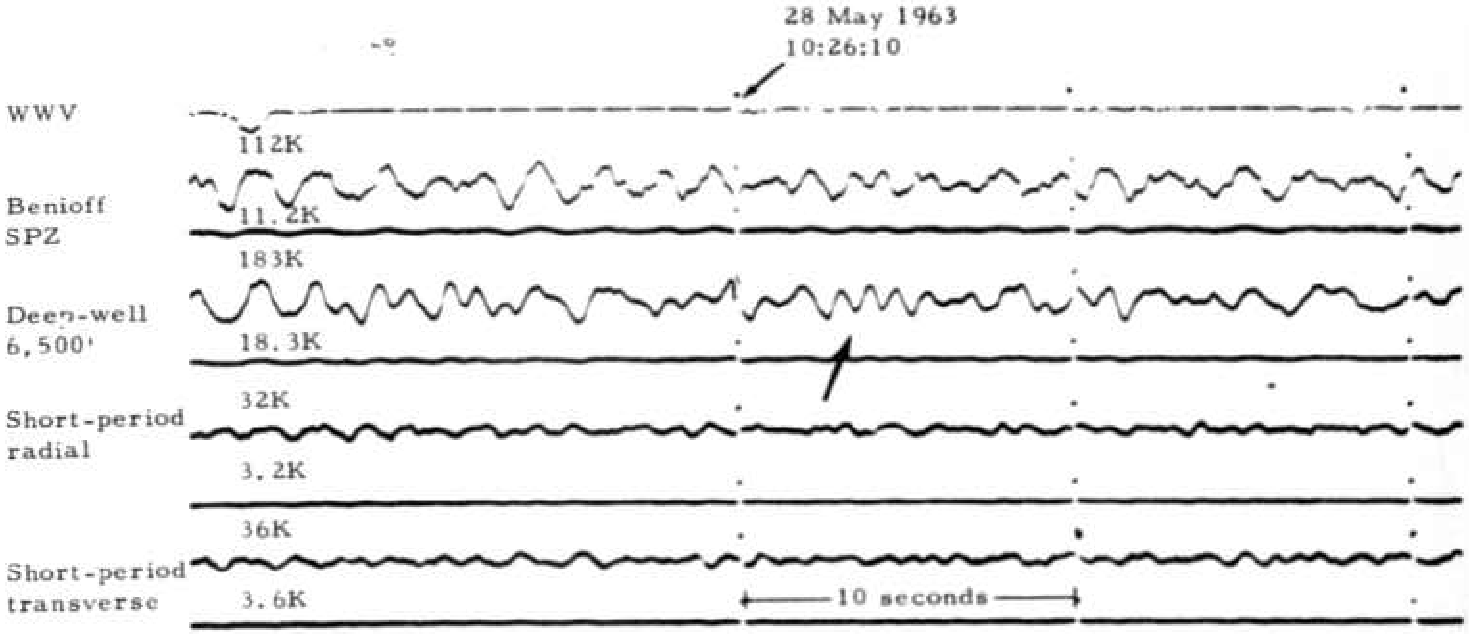


Figure 24. Develocorder record of small Benioff and deep-well seismometers at Orlando, Florida. Magnification at 1 cps (X10 enlargement). Noise sample showing first higher mode Rayleigh wave microseisms

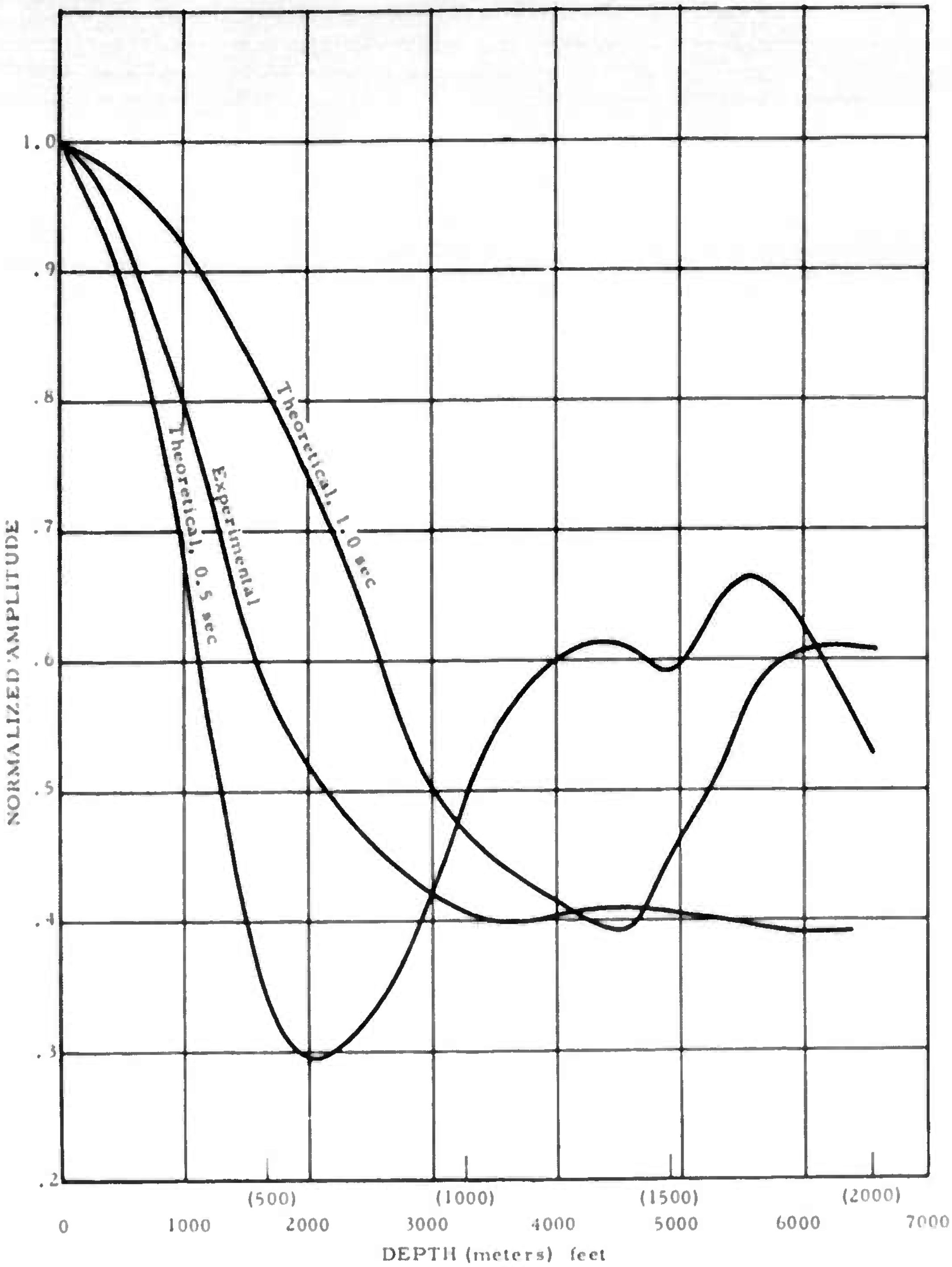


Figure 25. Theoretical amplitude of P waves with depth compared to the experimental results. The theory assumes a Ricker wavelet. Orlando, Florida

The experimental results agree reasonably well with the theoretical predictions as can be seen in figure 25. The main discrepancy occurs between 5000 and 6000 ft where the theoretical results indicate considerably larger amplitude than actually encountered in the well. The discrepancy may be explained by the difference between the actual shape of P waves and the Ricker pulse which the theory assumes.

Figure 26 shows the deep well-to-surface amplitude ratio of events received at 6,585 ft plotted against distance to the epicenter. As can be seen on this plot, there is no obvious relationship between distance to the epicenter and amplitude at 6,585 ft. The scatter of the data points is considerable and is probably due to one of the following:

a. Changes in amplitude caused by the interference of the noise with the signal;

b. The unconsolidated surface layer which may enhance signals that fall close to its natural period of vibration, thus giving abnormal high values of ground motion.

The few extremely large events received agree fairly well with the average, as can be seen on figure 26. For these events, the noise amplitudes are not large enough to appreciably distort the signal amplitude.

3.5 SIGNAL-TO-NOISE RATIOS

The increase in the signal-to-noise ratios with depth shown in figure 27 was obtained by dividing (point-by-point) the signal amplitude shown in figure 25 by noise amplitudes shown in figure 23. This technique is valid only if there is no major change in frequency content of the noise with depth. Due to the small change in frequency content below 1500 ft, the relative change in the signal-to-noise ratio between the different depths below 1500 ft is valid.

Between the surface and the depths below 1500 ft, the considerable change in frequency content of the noise indicates that the signal-to-noise improvement is frequency-dependent. For example, a signal of 0.5-sec period would be more clearly visible at depth, due to the lack of noise of this period, than at the surface where noise of this period is present. Considerations of this type indicate that for visual examination, the signal-to-noise improvement is larger than indicated in figure 27 for signals of periods below 1.0 sec.

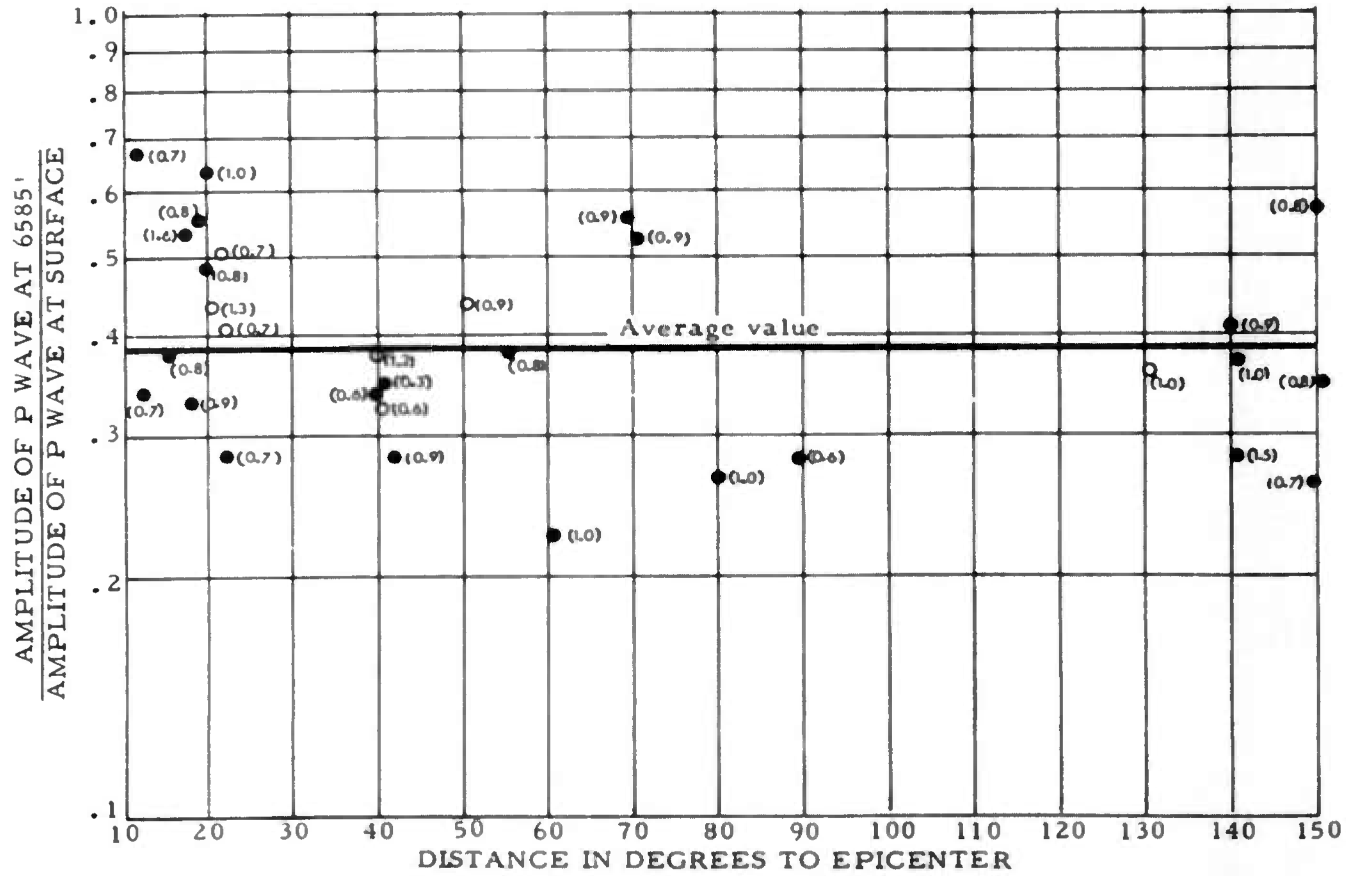


Figure 26. Plot of P-wave amplitude ratio against distance in degrees to epicenter.
O indicates an event of amplitude greater than 150 mu at the surface.
Period of the signal is given in parenthesis. Orlando, Florida

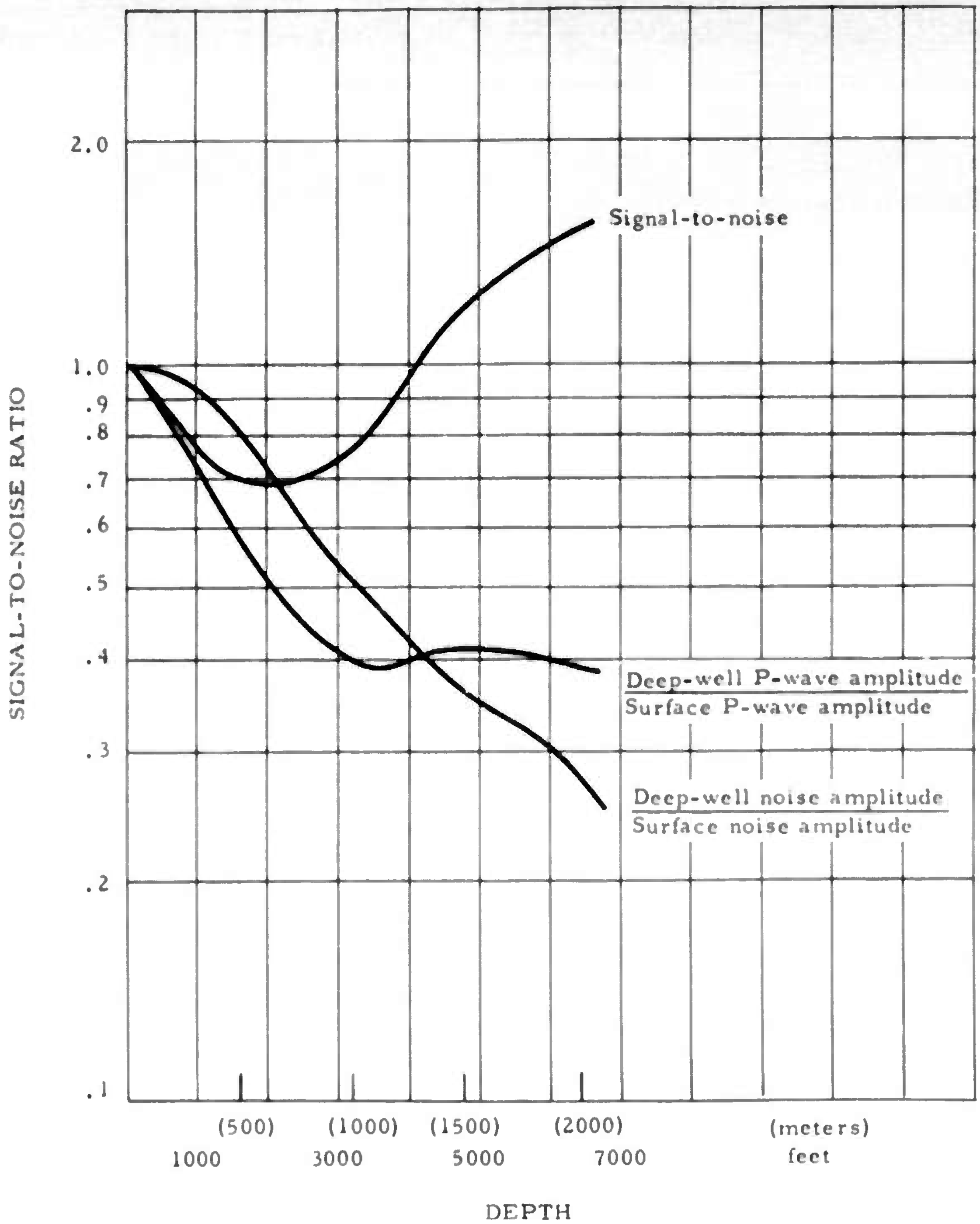


Figure 27. Signal-to-noise ratio versus depth, Orlando, Florida

Figures 28 and 29 show two events of completely different periods which illustrate the considerations discussed above.

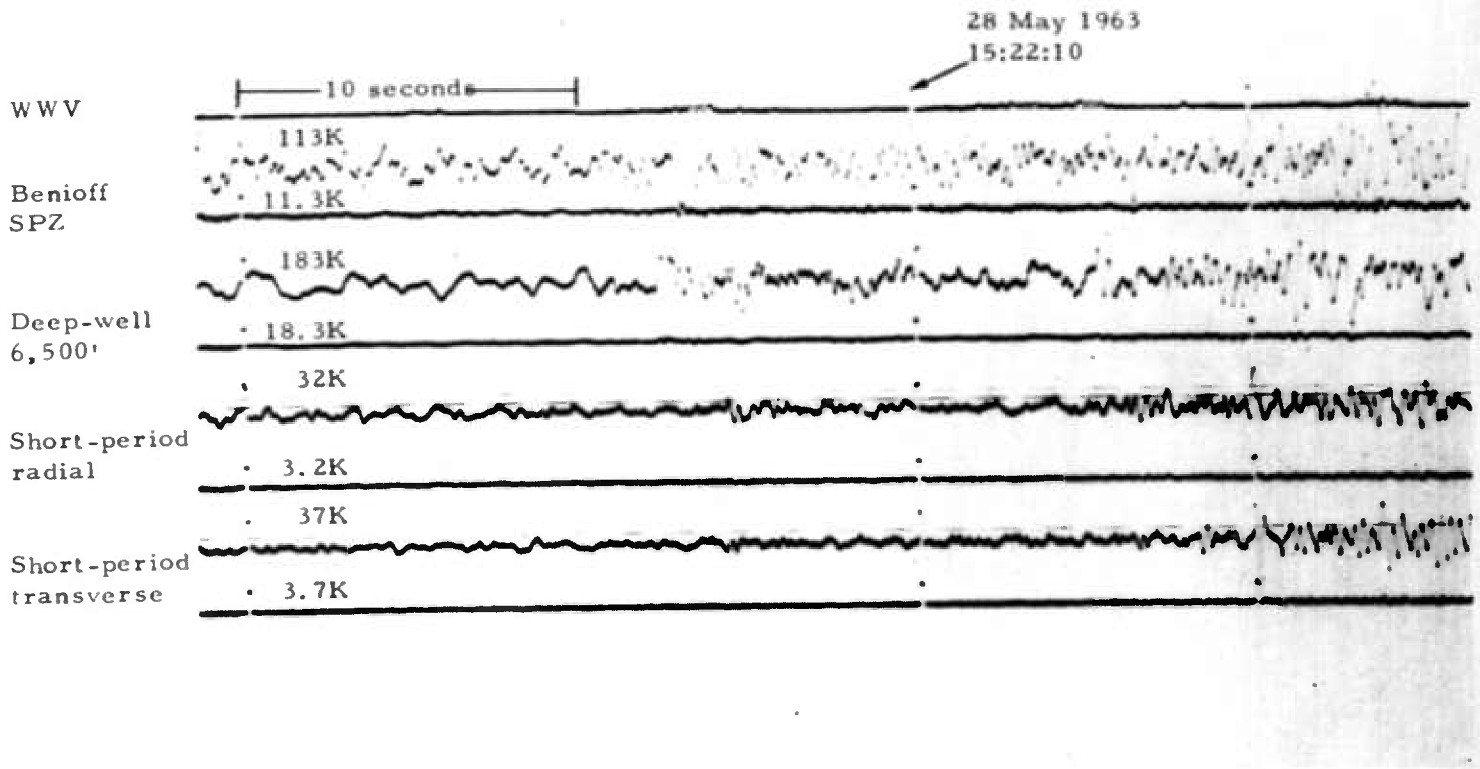


Figure 28. Develocorder record of small Benioff and deep-well seismometers at Orlando, Florida. Magnification at 1 cps (X10 enlargement).

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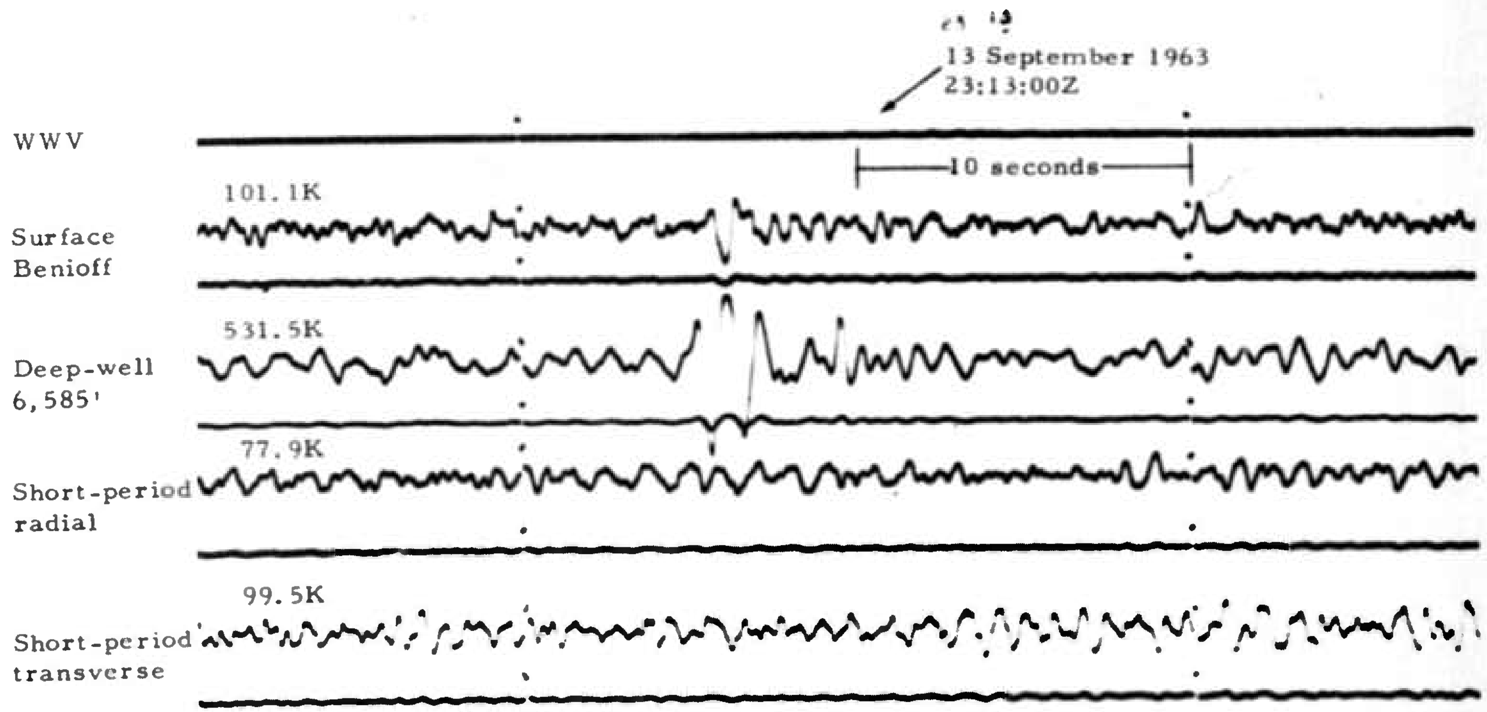

Figure 29. Develocorder record of small surface Benioff and deep-well seismometers at Orlando, Florida. Magnification at 1 cps (X10 enlargement).

APPENDIX 1 to TECHNICAL REPORT NO. 63-88

TERRY NO. 1 DEEP WELL SITE DATA

TERRY NO. 1 DEEP WELL SITE DATA

Location:	C SW/4 SE/4 Sec 21, Twp 23s, Rg 31E Orange County, Florida, 15 miles southeast of Orlando
Latitude:	28° 28' 01" N
Longitude:	81° 13' 17" W
Topo sheet:	Orlando NH 17-11
Elevation:	78' K. B. 65' G. L.
Lease:	Dated 1 April 1963 from Conway Land, Inc., covering 10 acres, for a period of one year.
Surface easements:	(a) Terry Cattle Co., Inc. (b) Culsman Corporation and Canlando Corporation (c) Anzac of Florida, Inc.
Access:	All weather roads to site
Power:	About 3.5 miles at Dean Road - no service at site
Telephone:	About 3.5 miles at Dean Road - no service at site
Site facilities:	(a) Previously existing well approximately 70 ft deep, cased, no overhead facility, located 90 ft from deep well. (b) Previously existing well approximately 400 ft deep, cased, no overhead facility, located 70 ft from deep well. (c) Concrete pad around deep well.

Cultural noise sources: (a) Dean Road, carrying light traffic, about 3-1/2 miles distant.

(b) City of Orlando activity about 8 miles distant.

(c) Cape Canaveral complex about 50 miles distant.

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